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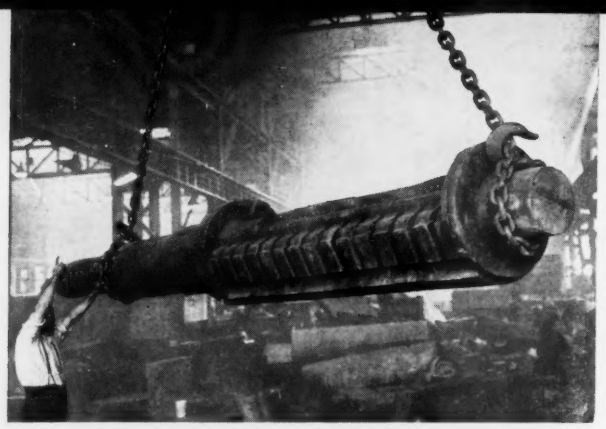

ALLOY CAST STEEL REEL SHAFT

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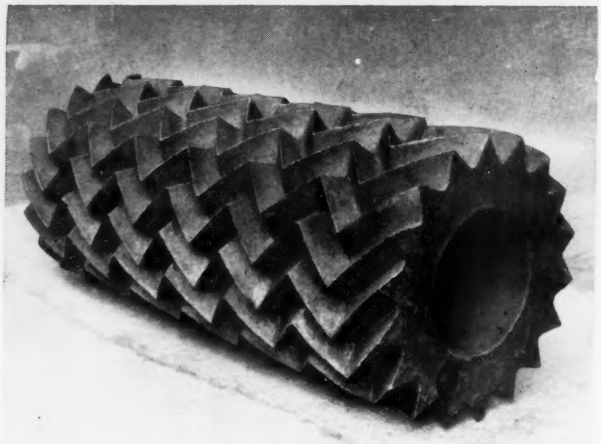

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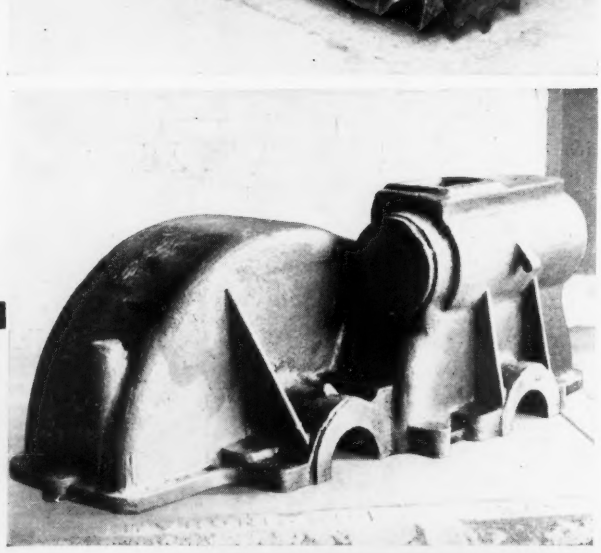
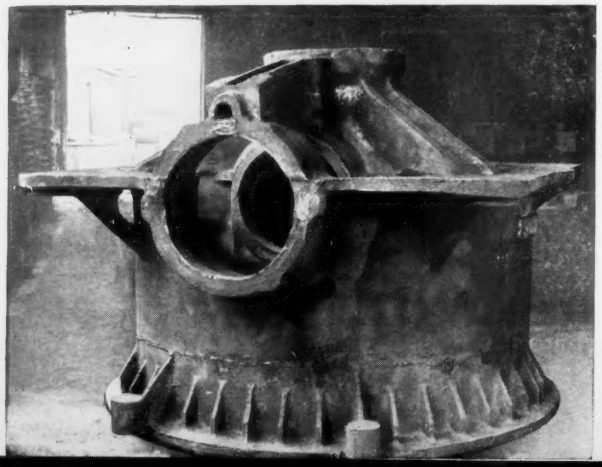


TOP HALF GEAR COVER

Certain sections of this casting must have a thickness of ¾" to very close limits. To match the lower half, overall dimensions must be maintained.



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ABBREVIATIONS AND SYMBOLS

A.	ampere(s)
A.hr.	ampère-hour(s)
Å.	Ångstrom unit(s) = 1×10^{-10} m.
A.C.	air-cooled; alternating current
A.H.	air-hardened
approx.	approximately
A.S.T.M.	Grain size (American Society for Testing Materials number)
at.-%	atomic per cent.
at.wt.	atomic weight
atm.	atmosphere(s) (pressure)
A.W.G.	American wire-gauge
° Bé.	Baumé (degree)
b.h.p.	brake horse-power
B. & S.	Brown and Sharpe (gauge)
B.o.T.	Board of Trade
b.p.	boiling point
B.T.U.	Board of Trade unit(s)
B.Th.U.	British thermal unit(s)
B.W.G.	Birmingham wire-gauge
° C.	centigrade; Celsius (degree)
cal.	calorie(s)
c.c.	cubic centimetre(s)
c.d.	current density
c.g.s.	centimetre-gramme-second unit(s)
cm.	centimetre(s)
coeff.	coefficient(s)
conc.	concentrated
const.	constant(s)
cu.	cubic
cwt.	hundredweight(s)
D.C.	direct current
dil.	dilute
dm.	decimetre(s)
D.P.N.	Vickers diamond pyramid hardness number
e.m.f.	electromotive force
eV.	electron volt(s)
° F.	Fahrenheit (degree)
ft.	foot, feet
ft.lb.	foot-pound(s)
g.	gramme(s)
gal.	gallon(s)
H.F.	high-frequency
h.p.	horse-power
h.p.hr.	horse-power-hour(s)
hr.	hour(s)
in.	inch(es)
in.lb.	inch-pound(s)
I.S.W.G.	Imperial standard wire-gauge
° K.	absolute temperature (Kelvin scale)
kcal.	kilogramme-calorie(s)
kg.	kilogramme(s)
kg.m.	kilogramme-metre(s)
km.	kilometre(s)
kV.	kilovolt(s)
kVA.	kilovolt-ampère(s)
kW.	kilowatt(s)
kWh.	kilowatt-hour(s)
kX.	crystal Ångstrom(s) = 1000 Siegbahn X-units
l.	litre(s)
lb.	pound(s)
L.F.	low-frequency
M.	molar (solution)
m.	metre(s)
mA.	milliampère(s)
max.	maximum
mg.	milligramme(s)
min.	minimum; minute(s)
ml.	millilitre(s)
mm.	millimetre(s)
m.m.f.	magnetomotive force
m.p.	melting point
mV.	millivolt(s)
mμ	millimicron = 1×10^{-9} m. = 10 Å.
N	normal (solution)
N.T.P.	normal temperature and pressure
O.H.	open-hearth; oil-hardened
O.Q.	oil-quenched
oz.	ounce(s)
p.d.	potential difference
pH	hydrogen-ion concentration
p.p.m.	parts per million
r.p.m.	revolutions per minute
sec.	second(s)
sp.gr.	specific gravity
sq.	square
S.W.G.	standard wire-gauge
T.	tempered
temp.	temperature
V.	volt(s)
VA.	volt-ampère(s)
W.	watt(s)
Wh.	watt-hour(s)
W.G.	water-gauge
W.Q.	water-quenched
wt.	weight
wt.-%	weight per cent.
yd.	yard(s)
μ	micron(s) = 1×10^{-6} m.
μg.	microgramme(s) = 1×10^{-6} g.
μμ	1 millionth micron = 1×10^{-12} m. = 0·01 Å.
Ω	ohm(s)
°	degree (arc or temperature)
′	minute of arc; foot (feet)
″	second of arc; (inches)
$<$	less than
$>$	greater than
$\not<$	not less than
$\not>$	not greater than
$\leqslant$	equal to or less than
$\geqslant$	equal to or greater than
$\neq$	not equal to
$\equiv$	identically equal to
$\cong$	approximately equal to
$\propto$	proportional to

LT.-COMDR. (E) G. W. WELLS, R.N.(Ret.), D.L., M.I.Mech.E.

GEOFFREY W. WELLS was born at Southfields in 1901, and was educated at Osborne and Dartmouth Royal Naval Colleges. From 1917 to 1924 he served with the Royal Navy, qualifying in engineering at Greenwich and Keyham Royal Naval Colleges.

In 1925 Lt.-Comdr. Wells was transferred to the emergency list of the Royal Navy, and in the same year he joined Executors of James Mills Limited, where he was successively manager of the bright-drawn steel department, of the rolling mills, and of the London Office of the Company. He was later appointed to the Board. He also held the appointment of Managing Director of the Mills Scaffold Company from 1939 to 1944.

Lt.-Comdr. Wells first joined The United Steel Companies Limited in 1944, as General Manager of the Monk Bridge Ministry of Supply factory. In the following year he became General Works Manager of the Appleby-Frodingham Steel Company, and in 1948 he took up his present appointment as Director and General Manager, in succession to Mr. W. B. Baxter. In 1954 he was elected to the Board of The United Steel Companies Limited.

A Member of The Iron and Steel Institute since 1945, Lt.-Comdr. Wells is President of the Lincolnshire Iron and Steel Institute for the Session 1954–55. He has kindly agreed to act as Chairman of the Reception Committee which is making the arrangements for the Special Meeting in Scunthorpe in October.

Lt.-Comdr. (E) G. W. Wells, R.N.(Ret.), D.L., M.I.Mech.E.
Honorary Member of Council, 1954–55

PAPERS AND REPORTS ON RESEARCH AND PRACTICE

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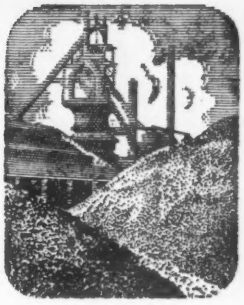


Developments in Ironmaking at Appleby-Frodingham

By G. D. Elliot

SYNOPSIS

Since ironmaking practice at the Appleby-Frodingham Steel Company was described in Iron and Steel Institute Special Report No. 30 in 1944, many improvements in the plant and fundamental changes in practice have occurred. The paper gives the reasons for these changes and explains why some of the views expressed in 1944 are no longer held by the author.

Improvements in sintering practice have led to an increase of sinter in the furnace burden to almost 100% with very considerable savings in the cost of iron.

The use of bosh tuyeres and the practice of frequent checking have led to an increase in furnace production.

Experiments and trials of various refractories have been carried out and successes and failures are recorded. 1165

Introduction

IRONMAKING at the Scunthorpe works of The United Steel Companies has always been based on smelting the local Frodingham ore, together with siliceous ore from South Lincolnshire and Rutland. The latter, because it occurs geologically in the Northampton series, is usually referred to as 'Northampton ore.'

The practice at Appleby-Frodingham was described in considerable detail in a report[1] published in 1944; this outlined the history of ironmaking at Appleby-Frodingham from its commencement in 1866 and dwelt at length on the practice existing in 1944.

It is now felt desirable and necessary to describe the practice and thinking of 1955. Both have altered considerably during the intervening years. In many ways, the present paper is a complete reversal of what was written in 1944. Many false theories and many cherished illusions have been destroyed by the always exciting, and sometimes painful, experiences of ten busy years. Changes in raw materials and the need to resolve serious operating problems are the only justifications for changed thinking and practice.

In 1944 the plant consisted of two furnaces at South Ironworks, four older furnaces at North Ironworks, and four old furnaces at Frodingham Ironworks. Typical operating results were given, and these have been reproduced and extended in Table I to include figures representing present practice.

Since 1944, further deterioration in ferruginous raw materials has occurred, which is shown in Table II. It will be seen that in addition to decreased iron content the ores now contain much more sulphur.

In 1944 an average of 33% sinter was used in the furnace and evidence was then given that 34–39% was the economical range of sinter in the burden. Today, every effort is made to use 100% sinter in the burden and an average of 95% has been smelted for more than two years. Work on the reducibility of sinter was described because, at that time, the reducibility test was considered important; today, this view is no longer held. It is proposed in the present paper to describe the reasons for these reversals in thinking.

In the manufacture of sinter, practice has changed in several directions and reasons for the more important of these changes will be given. In furnace design, two developments have taken place in the last ten years. One has been an increase in furnace throat diameter relative to bell diameter, and the other has been the reintroduction of bosh tuyeres. The latter development is also the result of a complete change of thinking. More precise views are held in regard to coke quality than were held in 1944. Any report on blast-furnace practice would be incomplete without reference to coke quality. Since 1944, many experiments and trials have been made in regard to refractories; some of the more important of these will be briefly mentioned.

Manuscript received 10th June, 1955.

Mr. Elliot is Works Manager (Iron) at the Appleby-Frodingham Steel Company, Scunthorpe.

Ten years ago, blast-furnace operation was primarily aimed at maintaining uniform stock descent, and much was written to justify this and develop theories on how best it could be obtained. One of the many features in this connection was the use of low blast temperatures. In 1944 it was said that the best furnace results were obtained with blast temperatures of about 430° C. Today, no attempt is made to achieve uniform stock descent. Indeed, efforts are made to discourage it and it is possible to use blast heats as high as 750° C.

In 1944 the major operating problems were scaffolds and hearth breakouts; today, scaffolds are unknown and furnace stacks are a problem because cutting back of stack lining is now being experienced. Only one hearth breakout has been experienced in the last 103 furnace years.

It will be obvious that in the last ten years many firmly believed theories have been discarded and many features of practice thought undesirable in 1944 have been adopted in 1955.

In the introduction to the earlier report, Mr. W. B. Baxter and the late Dr. T. Swinden concluded by saying:

> *" The advance of knowledge permitting the preparation of a paper in more definite terms will be hastened if the present paper produces constructive criticism."*

The ironworks staff at Appleby-Frodingham have been fortunate in receiving, during the decade that has passed, a great deal of constructive criticism and help from the research workers. This applies not only to people employed by The United Steel Companies, Ltd., but also to many friends in the industry throughout the world. The encouragement to thinking so obtained has been an important factor in arriving at present practice and operating results.

RECENT HISTORY OF IRONMAKING

Since 1944 the following new plant has been built:

Six sinter machines (two in 1951 and four in 1954)
A complete ore crushing and screening plant (1954)
Four additional ore driers (1951)

Table I

COMPARATIVE RESULTS OF APPLEBY-FRODINGHAM FURNACES
For 8-week periods during the years 1899–1955

	1899	1909	1919	1929	1939	1949	1954	1955
	Frod. No. 2	Frod. No. 4	North No. 8	North No. 6	South No. 9	Queen Mary	Queen Anne	Queen Victoria
Charging	Hand	Mech.	Hand	Mech.	Mech.	Mech.	Mech.	Mech.
Iron produced, tons/week	644	1065	694	1960	3326	3365	7044	7476
Coke consumed, cwt. per ton of iron	33·10	31·50	32·97	30·51	20·91	23·27	17·28	17·34
Burden consumed, cwt. per ton of iron	72·20	76·20	76·45	79·49	67·51	69·08	52·24	52·09
Flue dust produced, cwt. per ton of iron	0·50	7·62	1·12	5·68	0·49	3·72	0·99	1·56
Materials in Burdens, %								
Frodingham ore: Raw	78·4	90·6	29·55	29·58	33·11	38·3	1·5	1·6
Calcined			55·16	45·56				
Northampton ore: Raw		1·2	7·14	16·84	21·85	14·5		
Dried					16·08	21·8	1·6	1·9
Basic slag	2·1	3·1		2·05				
Cinder, scale, etc.	12·0	4·4	7·25	3·75		2·1	0·7	1·2
Foreign ore			0·70	1·87				
Scrap	1·0	0·7	0·20	0·35	0·13	0·3		0·4
Sinter					28·83	23·0	96·2	94·9
Flue dust	6·5							
Total	100·0	100·0	100·0	100·0	100·0	100·0	100·0	100·0
Iron Analysis, %								
Silicon	0·50	0·50	0·88	0·87	0·74	0·98	0·84	0·78
Sulphur	0·098	0·096	0·090	0·068	0·063	0·064	0·065	0·057
Phosphorus	1·94	1·85	1·80	1·75	1·55	1·54	1·40	1·48
Manganese	2·01	1·12	1·43	1·50	1·19	0·95	0·96	1·04
Slag Analysis, %								
SiO_2	31·50	32·30	31·70	31·35	33·10	32·16	33·27	33·94
Al_2O_3	15·90	16·55	15·68	17·74	18·97	19·33	18·94	19·23
MnO	3·57	2·48	1·72	2·19	1·23	1·07	1·28	1·30
CaO	44·70	43·90	43·50	42·90	39·90	40·85	40·15	40·30
FeO	1·63	1·13	0·82	0·54	0·59	0·66	0·69	0·75
Fe		2·24	1·75	0·81	0·80	1·26	0·94	0·88
MgO			3·48	3·83	3·07	3·17	3·80	3·64
S			1·22	2·12	1·50	1·84	1·44	1·42

Two beds and a second reclaiming machine added to the bedding plant (1951)
Two blast-furnaces, together with gas-cleaning plant and other auxiliaries (1954)
Four turbo-blowers with boilers (1954).

In addition, necessary additions and alterations to water-treatment and circulating systems have been carried out.

The following plant has, during the same period, been scrapped:

The whole of Frodingham Ironworks, comprising four blast-furnaces with all their auxiliary plant
The whole of North Ironworks, comprising crushing plant, four-pan Greenawalt sinter plant, a small ore-drying plant, and four blast-furnaces. The power generating station is still in operation.

BLAST-FURNACE BURDEN

The deterioration in the chemical quality of the Frodingham and Northampton ores was mentioned earlier (*see* Table II). The problem of arising fines became much more serious during the intervening years.

In 1944, and for several years following, every effort was made to maintain the production of fines ($-\frac{5}{8}$ in.) and consequently the percentage of sinter in the furnace burden at a minimum. Despite this, the amount of arising fines increased steadily as ore winning became located farther from the outcrop and became more mechanized. Underground mining was extended in the Frodingham district from 1946 and now about 25% of the Company's usage of Frodingham ore is from underground workings. Ore won by this method always contains more fines than ore loaded by face shovel in open-cast workings. Table III shows the steady rise in the amount of fines arising from existing mining, crushing, and screening methods.

It had been appreciated that, although drying of Northampton ore was introduced to improve screening efficiency, improvement in blast-furnace operation arose from the use of dried lump ore in place of wet lump ore. It had been realized for many years that lump ore to the blast-furnace should be as clean as possible. Several full-scale trials were carried out in 1947 to demonstrate this.[2] As a result of these trials, plant alterations were carried out in 1951 to permit drying of the whole of the Northampton ore, instead of only the natural fines. Additional screening capacity was installed to give the furnaces a clean lump ore charge.

About this time an interesting development was the use of gas-heated screens, after exhaustive trials with electrically heated screens, in order to improve screening efficiency. All these developments in screening and drying led to an improvement in furnace practice but left much still to be done.

In 1951 it was possible to charge the furnaces with clean oversize ore, of which the Northampton portion had been dried, together with a balancing proportion of about 42% of sinter. This amount of sinter was sufficient to maintain a balance of materials at the then obtaining amount of arising fines.

Furnace operation was still beset with the great majority of the difficulties existing in 1944. It was in regard to the balancing portion of sinter that the major problems of the ferruginous burden remained.

It is in connection with sinter manufacture that most work and experiment has been carried out, especially in the years 1947–1952. Early trials to decrease the amount of returned fines, or circulating load, in the sintering process led to the realization that unusually hard and strong sinter could be made if the amount of return fines was actually increased. Today, the circulating load is approximately 40%, compared with the desired 15–20% of 1954. Some very interesting results were obtained on the furnace when the sinter in the burden was made up of doubly sintered material. Attempts to attain similar sinter quality without wholly resintering led to the realization that the sinter plant was as particular in regard to the size grading of its raw material as the blast-furnace always had been. It had been established[3] as early as 1929 that the blast-furnace did not like material smaller than about $\frac{3}{8}$ in.

Some of the Frodingham ore contains as much as 40% calcium carbonate, all of which is present as calcitic fossils. In pieces as large as $\frac{1}{2}$ in., the calcite merely changes to lime in the sintering process and is not fixed in any way. Exposure to water, or to the atmosphere, of sinter containing free lime leads to hydration of the lime and thence to disintegration

Table II

TYPICAL ANALYSES OF FRODINGHAM AND NORTHAMPTON ORES

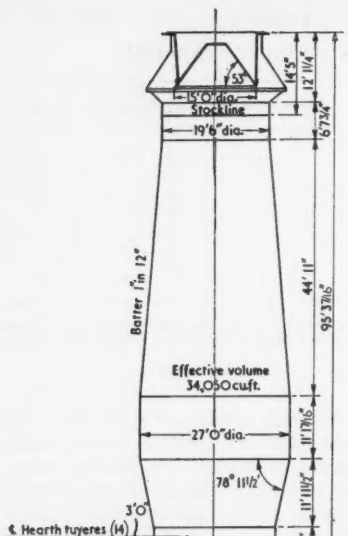
As Received	Frodingham		Northampton	
	1943	1954	1943	1954
H_2O	9·80	11·00	17·10	16·90
Fe_2O_3	21·80	19·90	46·96	35·02
FeO	6·65	7·24	0·37	6·41
SiO_2	6·22	6·72	12·88	14·79
Al_2O_3	3·96	3·81	6·69	7·54
CaO	20·57	21·72	2·28	3·32
MgO	1·51	1·45	0·50	0·91
P_2O_5	0·823	0·881	1·36	1·54
Equiv. P	0·360	0·383	0·592	0·672
MnO	1·25	1·41	0·19	0·17
Equiv. Mn	0·97	1·19	0·15	0·13
S	0·297	0·406	0·021	0·124
CO_2+comb. H_2O	24·33	24·81	11·14	13·09
Loss on ignition	26·10	23·95	13·40	13·51
Total Fe	20·40	19·48	33·16	29·50

Table III

FINES ARISING, 1929–1954

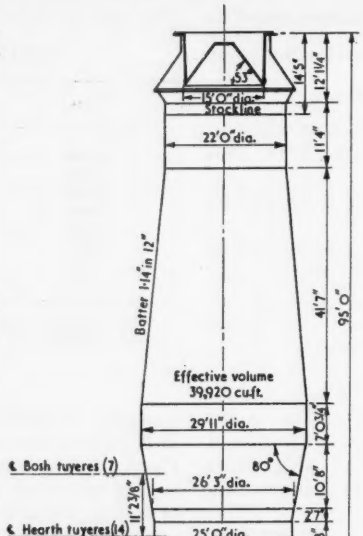
Year	Fines after Crushing to approx. 2½ in., %
1929	25
1938	30
1939*	40
1947	45
1951	52
1952	54
1954	58

* The abnormal increase was due to the starting-up of the more efficient crushing and screening plant at South Ironworks in May, 1939.



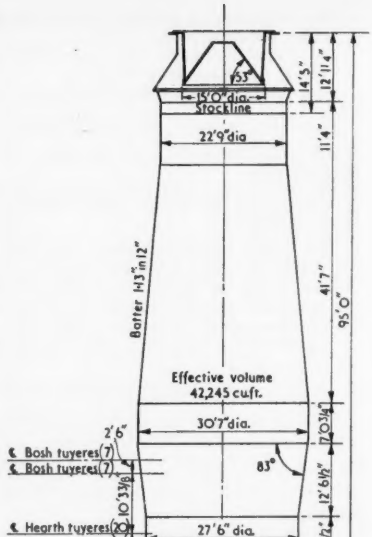
(*a*) *Queen Mary* (1939)

	Area	Volume
Hearth	380·13 sq. ft.	3247 cu. ft.
Bosh	572·56 sq. ft.	5696 cu. ft.
Top	298·65 sq. ft.	1985 cu. ft.
Bell	176·71 sq. ft.	...
Stack	...	26,410 cu. ft.



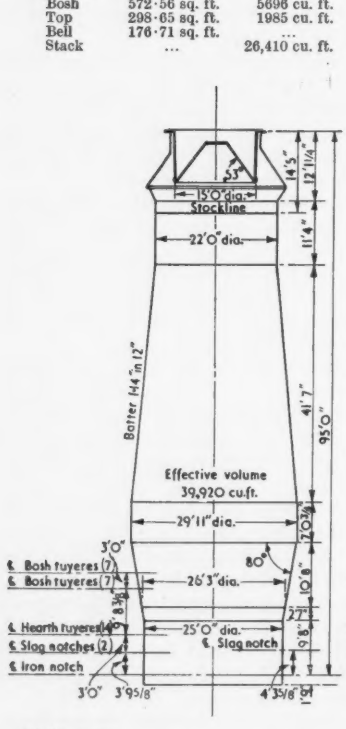
(*b*) *Queen Mary* (1951)

	Area	Volume
Hearth	490·87 sq. ft.	4745 cu. ft.
Bosh	703·30 sq. ft.	7933 cu. ft.
Top	380·13 sq. ft.	4306 cu. ft.
Bell	176·71 sq. ft.	...
Stack	...	27,150 cu. ft.



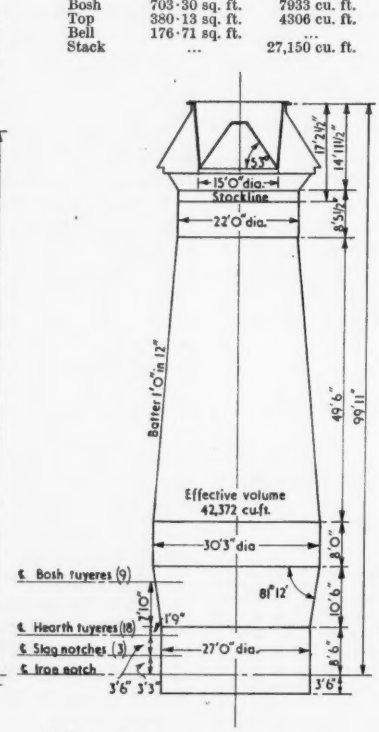
(*c*) *Queen Mary* (1956: proposed)

	Area	Volume
Hearth	594·0 sq. ft.	6200 cu. ft.
Bosh	734·0 sq. ft.	8320 cu. ft.
Top	407·0 sq. ft.	4670 cu. ft.
Bell	176·71 sq. ft.	...
Stack	...	28,540 cu. ft.



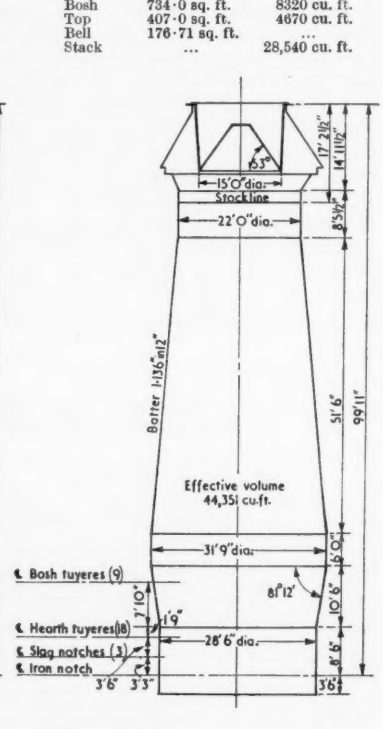
(*d*) *Queen Bess*

	Area	Volume
Hearth	490·87 sq. ft.	4745 cu. ft.
Bosh	703·30 sq. ft.	7933 cu. ft.
Top	380·13 sq. ft.	4306 cu. ft.
Bell	176·71 sq. ft.	...
Stack	...	27,150 cu. ft.



(*e*) *Queen Anne*

	Area	Volume
Hearth	572·56 sq. ft.	6871 cu. ft.
Bosh	718·69 sq. ft.	6757 cu. ft.
Top	380·13 sq. ft.	3230 cu. ft.
Bell	176·71 sq. ft.	...
Stack	...	32,285 cu. ft.



(*f*) *Queen Victoria*

	Area	Volume
Hearth	637·9 sq. ft.	7655 cu. ft.
Bosh	791·73 sq. ft.	7484 cu. ft.
Top	380·13 sq. ft.	3230 cu. ft.
Bell	176·71 sq. ft.	...
Stack	...	33,423 cu. ft.

Fig. 1—Development of furnace lines at South Ironworks

of the sinter. Experiment and trial showed that most of the lime could be fixed or combined if the ore fines for sintering were smaller than $\frac{1}{4}$ in.

It is believed that the reasons for this are associated with the carbonate nature of the ore. Coke breeze, in sintering, has to drive off large quantities of CO_2 and water of crystallization before it can perform its main duty of sintering the ores.

If the size of the ore particle is larger than $\frac{1}{4}$ in., the presence of large discrete pieces of calcite or other carbonate prevents uniform sintering; if excess fuel is used, the phenomenon of slagging prevents complete sintering, as in such a case the slag layer formed prevents sintering taking place beyond this point. With sinter of low iron content, complete sintering to the verge of slagging is necessary to obtain good mechanical strength. Complete evolution of CO_2 and fixing of the resultant free lime is necessary to obtain freedom from dust. These two demands can only be satisfied if the ore is $-\frac{1}{4}$ in. in size.

Accordingly, in the programme of plant extension of 1950–1951, a third stage of crushing was introduced into the process. Lump ore for the blast-furnace was doubly screened at $\frac{5}{8}$ in. and the resulting fines were screened for the sinter plant at $\frac{1}{4}$ in. The fraction between $\frac{1}{4}$ in. and $\frac{5}{8}$ in. was reduced to $-\frac{1}{4}$ in. by means of swing hammer mills. The importance of this change in practice can hardly be overemphasized. The cleaning of the oversize by improved screening was a logical development in the practice of ore preparation. The preparation of the burden for the sinter plant was a complete departure from all existing practice. Perhaps more than any other single factor, this led to the sinter plant being regarded as equally important as the blast-furnace itself.

The sinter plant was now regarded as a main production department and not as a sub-department of the blast-furnace plant. Certainly, from this time onwards, as much attention, both in regard to operation and research, was devoted to sinter-making as to ironmaking. No apology is made for the following quotation from the earlier report (*op. cit.*,[1] p. 64):

> *" It is hoped that someday the old idea that sinter is a necessary evil will pass and true appreciation will be given to the role of sinter in the need for a superior product. For this to be achieved, more detailed consideration must be given to all the many factors involved in sinter production."*

During the ten years since these words were written, many new factors in the production of satisfactory sinter have emerged and are still emerging.

The problems of increasing amounts of ore fines and of making satisfactory sinter led to the realization that additional sintering capacity was necessary—indeed, was already (1947) overdue.

Until more sintering capacity was provided, a clean ore burden could only be achieved by sacrificing all thoughts of making good sinter and operating the sinter plant at a rate which could only lead to the furnace receiving an even poorer product than was already the case. The only alternative policy was to discard fines to stock, until sintering capacity became available. From November, 1947, to October, 1951, 1·20 million tons of ore fines were stocked. The resulting piles were indeed the Company's monument of faith in sintering. The whole of this stock was liquidated between January, 1952, and July, 1954.

Plant trials and research on sinter-making were carried out fairly continuously from 1946 onwards. A classic paper by Voice *et al.*,[4] based on work carried out at Appleby-Frodingham, probably represents the first attempt at setting out in a scientific manner the problems of large-scale sinter production. The results obtained were not only of value when applied to the existing plant, but also served as an invaluable basis of design for the plant which came into operation during 1954.

In 1945 serious consideration was given to finding an alternative to sintering. Full-scale trials were carried out to evaluate briquetting as a commercial process. The results were completely negative but were of considerable value in leading to a stronger attack on the problems of sinter-making.

It must be confessed that until 1951, the furnace operating staffs were much happier as the amount of sinter they had to smelt was reduced. Sinter, because of its many shortcomings, was regarded as a hindrance rather than a help. Sinter was still the price the ironmakers had to pay for a clean lump-ore burden.

A particularly important trial was when No. 10 furnace was operated on a specially prepared burden. The lump ore used was screened three times to ensure perfect cleanliness. The sinter used was manufactured by making sinter in the ordinary way and then resintering it to secure strength and freedom from dust. This resulted in, what was at that time, a record furnace performance. This trial was important because it was obvious that the furnace was benefiting both from its super-clean ore burden and from its strong, and therefore cleaner, sinter.

This strong sinter, by all existing standards, was extremely irreducible. But the furnace, working at a very low coke rate, said otherwise. This test finally destroyed any faith the operators still had in the value of the standard reducibility tests.

With sinter containing a low iron content (and therefore a high content of slag-making minerals) it is impossible to make an oxidized sinter of the Swedish type. Appleby-Frodingham sinter, by Swedish standards, is heavily slagged and in a low state of oxidation. If the low-iron-content sinter was made so as to be easily reducible by laboratory tests, it would be so weak and contain so much dust as to cause very poor furnace performance. It is impossible to lay down a universal standard of sinter quality. Quality is dictated by the raw materials used.

In 1951 it became necessary to take stock. It was known that a clean ore burden, without sinter, gave a fast, freely moving furnace with what was then a fairly good coke consumption. To secure such a clean ore burden, the fines discarded were more than 50% of the incoming iron ore. It was obviously out of the question to discard as permanent practice such a large percentage of raw material. Resintered sinter was obviously a most desirable blast-furnace feed, but to produce it and deal with all the arising ore fines would mean that existing sinter plants would have to be more than doubled in capacity for the same tonnage of iron production. Even at this time

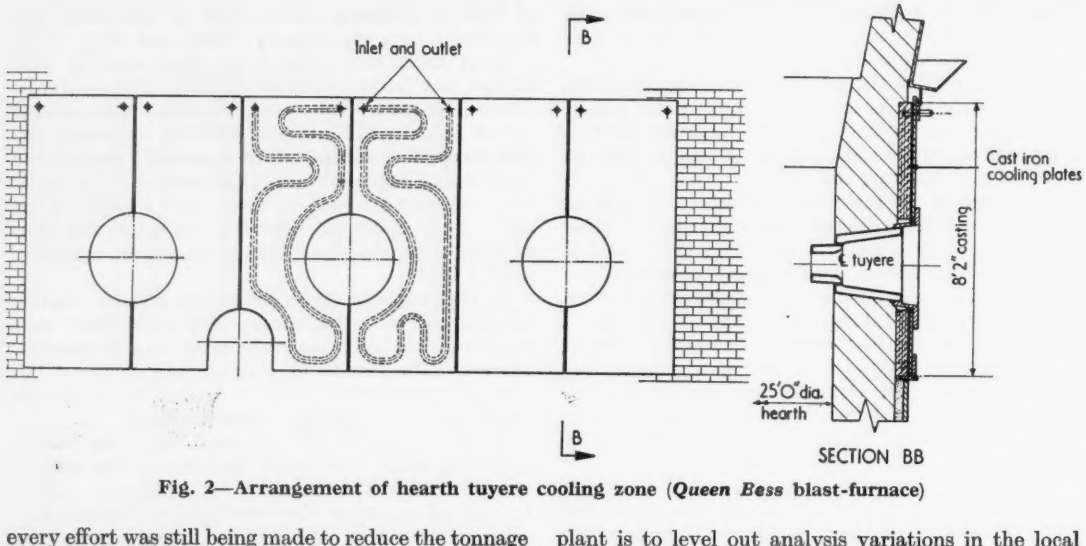


Fig. 2—Arrangement of hearth tuyere cooling zone (*Queen Bess* blast-furnace)

every effort was still being made to reduce the tonnage of ore it was necessary to sinter.

Now, for the first time, the operators began to estimate what it would mean if more than the balancing amount of sinter was used in the furnace burden. Considerable progress had been made in producing a cleaner and stronger sinter, and full-scale trials were initiated to determine the effect of increasing the percentage of sinter in the furnace. As much as 50% sinter had been tried in 1941 (*op. cit.*,[1] p. 48) and the results from every point of view were very discouraging.

In 1951 it was realized that in the near future it would be necessary to balance arising fines with a sinter usage of more than 50%. Accordingly, during the early part of 1952, the amount of sinter in the burden was progressively lifted until, in the first week in June, a furnace was operating at 100% sinter. This particular development has been fully described elsewhere.[5]

As a result of all the work summarily described, the plant additions which came into operation in 1954 were designed to provide a wholly sintered burden for the production of approximately 1¼ million tons of pig iron a year. The principal modifications built into the new sinter plant comprised:

(i) A greater area of sintering grate
(ii) More generous fan power
(iii) Efficient means of air-cooling the sinter
(iv) The ability to carry as high as 50% circulating load without sacrificing output
(v) Three-stage crushing of all incoming ore so that the sinter plant received nothing larger than ¼ in.
(vi) Complete instrumentation
(vii) More generous mixing facilities than had previously been installed.

In 1939, an ore-bedding plant was installed to blend the lump ore used in the furnaces. On the adoption of high sinter burdens, the flow of Frodingham ore to the older sinter plant was modified so that the ore, before tertiary crushing, passed through the bedding plant. What little lump ore is used is still blended, but the main purpose of the bedding plant is to level out analysis variations in the local ore feed to the sinter plant.

That all this work was worthwhile is demonstrated by the production figures given in Table I.

SINTER COOLING

After sinter has been made, it is obviously desirable to transport it to the furnace bins by means of a belt conveyor. The economic and operational advantages are well known. This demands that the sinter be cooled to less than 150° C. If the sintering machine is fully utilized for sintering, the product will leave the machine at a temperature of 800–1000° C. For many years, water-quenching was used but was always known to be unsatisfactory. In a low iron-bearing sinter, the bond is essentially a glass, and quenching led to almost explosive disruption.

The work of Voice *et al.*[4] gave the fundamental requirements for satisfactory cooling of sinter by means of air. In 1954, sinter coolers of an original design were put to work with extremely satisfactory results.

It has been possible to compare sinter of similar analysis and characteristics, air-cooled and water-quenched, in full-scale blast-furnace operation. With the two larger furnaces at Appleby-Frodingham, the air-cooled sinter leads to an increased iron production of almost 100 tons/day and a reduction in coke consumption of about 50 lb./ton.

It is possible that the benefits of air-cooling would not be as great with a high-iron-content sinter, because of the absence of glass bond. If so, it again emphasizes that sinter quality is dependent on the raw materials used.

Air-cooling, which is comparatively inexpensive, can be justified by the improved working conditions around the plant, by the lower cost of plant maintenance, and by the longer life of conveyor belts.

BLAST-FURNACE PLANT DESIGN AND LAYOUT

To overcome the problems of scaffolds, many attempts were made by modifications of the lines of

the ten furnaces. Some of the designs tried during the ten years before 1954 were undoubtedly ' freaks.'

No solution was to be found by altering the profile of the furnace. The only permanent development stemming from this work is an increase in throat diameter; Fig. 1 shows the lines of a 22-ft. furnace as it was in 1944, enlarged to 25 ft. in 1952, and as it will be after the next reline, enlarged to 27 ft. 6 in. The other major change in profile is in the steepened bosh angle, but this has arisen much more in securing greater volumetric capacity than in fitting the lines to the practice. For the sake of completion, the lines of the two furnaces commissioned in 1954 are also given. (It should be noted that the former Nos. 9 and 10 furnaces are now known as *Queen Mary* and *Queen Bess*, respectively.)

At the risk of being controversial, experience with different lines, with clean furnaces, and with scaffolded furnaces leads to the thought that, within wide limits, furnace lines are comparatively unimportant, provided that the raw materials charged are correctly prepared.

The effects of ore preparation and of coke quality are much greater than minor changes in bosh angles, stack batter, and the other details so dear to furnace designers.

Hearth and Bosh Jackets

All furnaces now use carbon-lined boshes with spray-cooled welded-steel jackets. This cheap type of construction has been found completely satisfactory for many years. The hearth-cooling on the 25-ft. furnaces is also by spray-cooling. On the larger furnaces cast-iron staves are used, but it is possible that the future will see spray-cooling adopted at these furnaces.

A development of some importance has been the introduction of cast-iron staves in the section of the furnace between the bottom of the bosh and the top of the hearth jacket. The arrangement is shown in Fig. 2. Figure 3 shows the very clean construction obtained, especially when the new construction is contrasted with the old. This type of construction originated at No. 10 furnace, Gary Works, United States Steel Corporation, and the author is greatly indebted to that company.

It is usual to allow for expansion in the casing steelwork of a blast-furnace. For example, expansion joints are usually provided at either top or bottom of the bosh jacket. It is now believed that it is quite safe to omit this provision. So long as the steel jackets are adequately cooled there should be no thermal expansion. A continuous rigid steel casing, from the top deck down to the foundations, has much to commend it. The nuisance of gas leaks, especially important when operating at high blast pressures, is certainly much reduced.

It is also now standard practice to close the bottom of the hearth by means of a steel plate resting on the lower brickwork and welded to the bottom of the hearth jacket. Experience indicates that this certainly reduces the infiltration of air and moisture, both of which are undesirable, whether carbon or ceramics are used in hearth construction.

Throat Armour

As the scaffolding trouble was overcome, scouring of linings has made itself felt, and as stack linings have been reduced in thickness to secure a larger furnace volume, more trouble has been encountered with throat linings than ten years ago. It must be confessed that no solution is at present in sight.

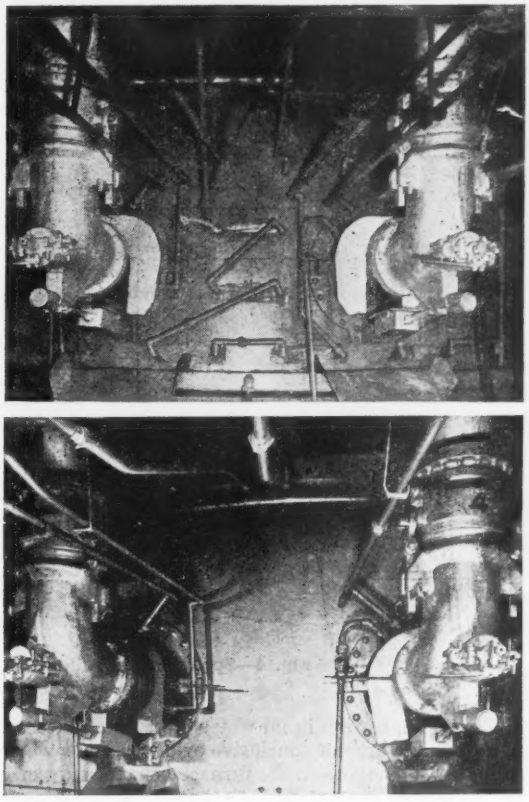


Fig. 3—Hearth tuyere cooling zone (*Queen Bess* blast-furnace)

One interesting large-scale experiment was the so-called ' tin-top.' During the exciting development work before 1954, it became possible that the furnaces at North Ironworks might have only a limited life in front of them. When No. 5 furnace became due for relining early in 1954, an experimental top was built in. Had this proved to be a complete failure it would have been possible to revert to normal conditions with a stoppage of only a few days. The furnace blew for nearly six months before it became redundant and was abandoned for scrapping. The experiment consisted of using no lining whatever in the upper 20 ft. of the stack. Instead, a welded mild-steel shell, spray-cooled on the outside, was used. The design and appearance of the ' tin-top ' are shown in Figs. 4 and 5.

It was a rather unnerving experience to stand on the access platform when a charge was dropped from the big bell; the noise of 13 tons of furnace burden impacting on the inside of a $\frac{3}{4}$-in. steel-plate shell had to be heard to be realized.

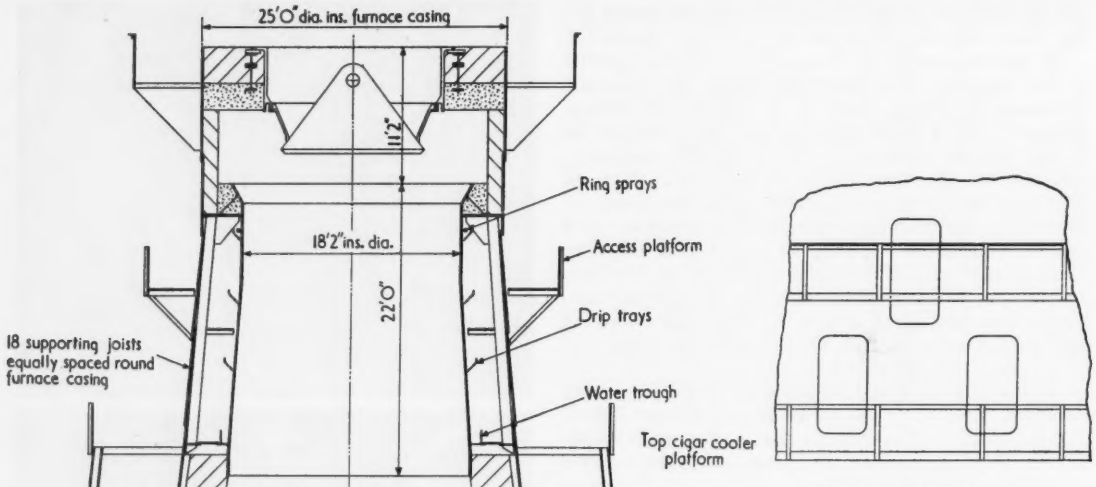


Fig. 4—Spray-cooled mild-steel throat lining (No. 5 blast-furnace)

Furnace operation in no way suffered. The results of six months are not conclusive evidence, but by any standard of comparison the furnace behaved no worse and gave no poorer results than that particular furnace had done for similar periods in previous campaigns. Coke consumption was certainly no higher, indicating that the intensive cooling of this part of the furnace was not affecting the thermal requirements of iron-making. It is an interesting thought that it is probably safe to apply external cooling to the stack of a blast-furnace until the exit gases fall below dew-point temperature.

The only trouble encountered with the ' tin-top ' was cracking of the vertical welds in the lower 3–4 ft. This was caused by the temperature changes which arose when the furnace went off blast for more than a short period. Shortly before the furnace was blown out it looked as if this problem had been overcome by allowing the cracks to develop, leaving them open, and then covering them with half-sections of tube welded to the steel plates. This construction gave a little mechanical flexibility. There is no doubt in the author's mind that a ' tin-top ' could be designed on the basis of this experience to give satisfactory service in a blast-furnace.

When the furnace was blown-out the ' tin-top ' was drilled comprehensively and no detectable wear had taken place. Even if wear should take place, it would be a comparatively easy matter to repair the resulting holes by welding on patches.

The use of the ' tin-top ' was suggested by the fact that conventional throat armour consists of steel members exposed to normal furnace temperatures and insulated at the back with refractory bricks and concrete. The question still remains unanswered of why, if steel is required, refractories are needed behind. Conversely, if refractories are required, why have steel in front ? The problem of upper throat construction still requires a great deal of attention.

Casthouse Layout

The casthouse layout provided with the first furnaces at South Ironworks in 1939 proved over the years to be very satisfactory. As furnace outputs (and therefore slag outputs) have risen, it has been found desirable to add a third slag notch at these furnaces. The 1954 furnaces were built with three slag notches.

The general plan of the 1954 casthouse is shown in Fig. 6. A notable improvement on the 1939 layout has been the provision of office accommodation, etc., between the hoist houses, as the plan shows.

The 1939 casthouse layout was designed to deal with a total production from the two furnaces of 7000 tons of iron and 9000 tons of slag per week. The fact that over 10,000 tons of iron and 13,000 tons of slag has been satisfactorily dealt with gave the Company sufficient confidence to repeat the same principles in the 1954 design.

It was suggested that a ' face-to-face ' casthouse was unsuitable for large tonnages and that an echelon arrangement would be better. The adoption of echelon casthouses would have been very difficult and would certainly have ruined the general plant layout. The decision to adhere in 1954 to the ' face-to-face ' arrangement has been justified by results. Up to 17,000 tons of iron and 22,000 tons of slag has been dealt with in one week without difficulty, and there is no doubt that larger tonnages can be handled satisfactorily. Over 9000 tons of iron, together with 11,500

tons of slag, have been handled from one furnace in a week.

A further interesting feature has been the introduction of a control pulpit fully equipped with instruments, in a commanding position of the furnace concerned. The view is now held that blast-furnace operation and ship operation have much in common; in both, things can happen with alarming speed and it is necessary that somebody be always available in charge of the controls to meet such emergencies. Accordingly, this control pulpit is manned by a staff-grade assistant at all times.

Bosh Tuyeres

In 1944 the author concluded some notes (*op. cit.*,[1] p. 85) about bosh tuyeres by giving an estimate that bosh tuyeres increased the coke consumption of a furnace by about 4% and by the statement that "*bosh tuyeres can be useful in securing larger outputs if the furnace design is incorrect, or if very limey slags have to be used.*"

In June, 1951, bosh tuyeres were reintroduced at Appleby-Frodingham into No. 1 furnace. At that time, the pig-iron shortage was acute and furnace operators were driven to any expedient which would increase production. Bosh tuyeres were reintroduced purely as an attempt to get more pig iron. At this time the risk of an increased coke consumption was considered worthwhile.

By the end of 1952 every furnace at Appleby-Frodingham had been equipped and was using bosh tuyeres. The furnaces built in 1954 were designed with bosh tuyeres which have been in constant use since blowing-in. Whether furnace design is incorrect or whether too limy slags are being used is doubtless a matter for debate. Slag analyses are given in Table I and the furnace lines are shown in Fig. 1. But the fact remains that the most cautious estimate indicates that bosh tuyeres have increased production by at least 10%. It is impossible, by the most careful examination of the data, to say that bosh tuyeres have increased coke consumption. Present-day coke consumptions, bearing in mind the high slag volume, do not appear excessive.

It is believed that the theory of bosh tuyeres may be explained by looking at the shape of a blast-furnace and noting the location of the hearth tuyeres. It seems obvious that under any conditions a smaller amount of blast will pass up the walls immediately above the bosh than up any other section of the furnace. Bosh tuyeres correct, or partially correct, this defect. This is indicated by the fact that the introduction of bosh tuyeres at all furnaces has led to a marked increase in the temperature of the shell immediately above the mantle. The proportion of the air which passes through the bosh tuyeres and the hearth tuyeres respectively is still being investigated.

At No. 1 furnace, equipped with ten 6½-in. dia. tuyeres and five 4-in. dia. bosh tuyeres, investigation has shown that about 20% of the total air blown entered the bosh tuyeres. The increase in output was of nearly the same order.

Measurements with bosh tuyeres open and with bosh tuyeres closed indicate that about 20% more total air can be blown at the same pressure, with bosh tuyeres open.

Fig. 5—'Tin-top' in position on No. 5 blast-furnace

The number of bosh tuyeres at all furnaces is equal to half the number of hearth tuyeres, and bosh tuyeres are located vertically between hearth tuyeres. The standard diameter of a hearth tuyere is now 6½ in. or 7 in. The standard diameter of a bosh tuyere is 4 in. A typical arrangement of hearth and bosh tuyeres is

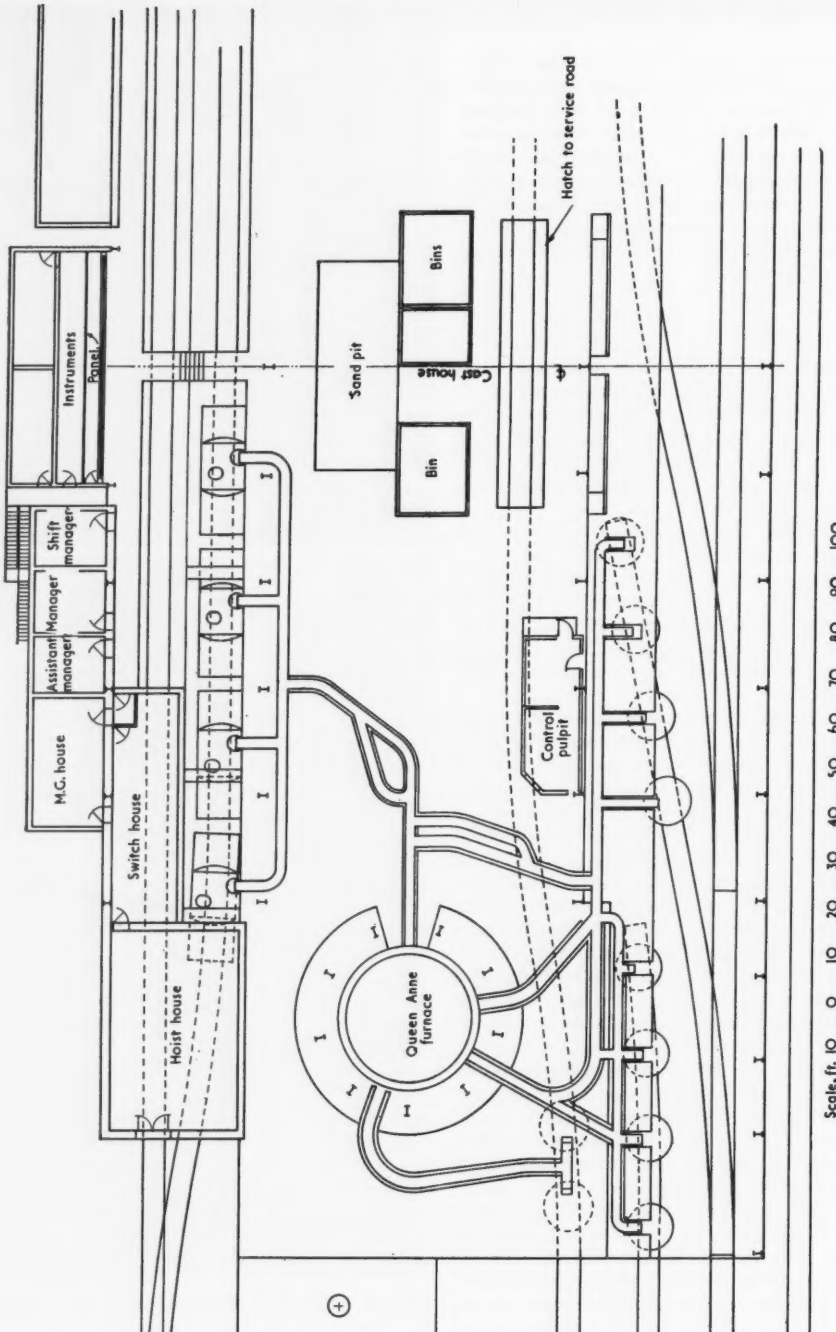


Fig. 6—General plan of casthouse (*Queen Anne* blast-furnace)

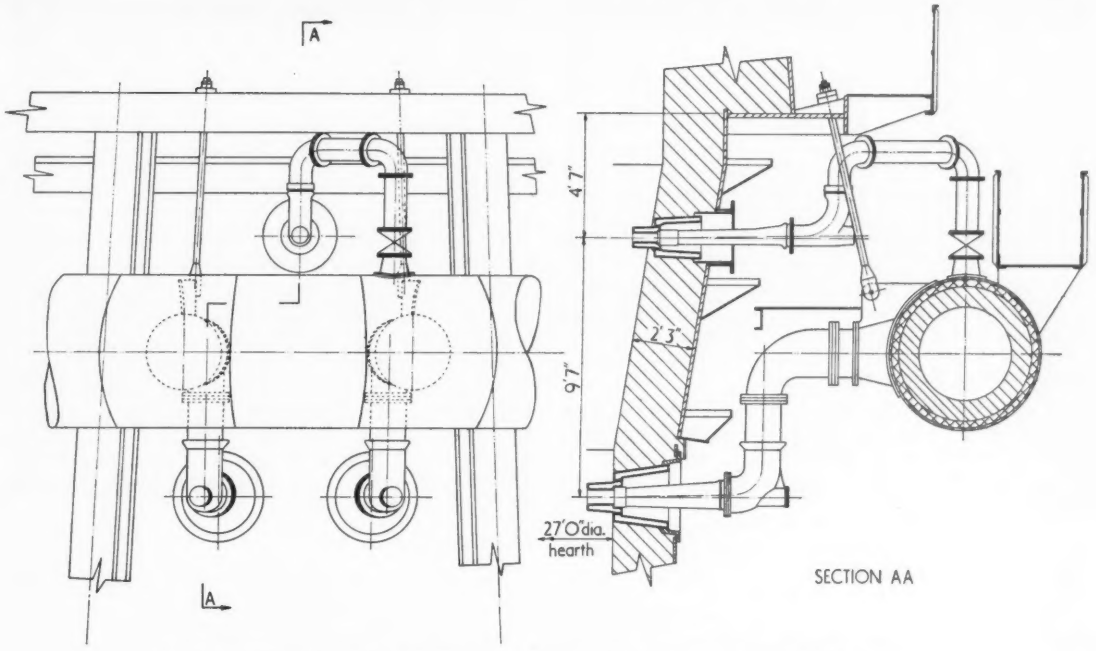


Fig. 7—Arrangement of hearth and bosh tuyeres (*Queen Anne* blast-furnace)

shown in Fig. 7. The results with bosh tuyeres have been extremely encouraging.

If it has done nothing else, the use of bosh tuyeres has directed attention to the lack of knowledge existing on the subject of air flow through tuyeres. If bosh tuyeres are fitted and prove to be wrong, it is simple to clay them up. The fitting of bosh tuyeres is one of the few fundamental changes possible to a blast-furnace which is neither irrevocable nor expensive.

The literature of ironmaking contains very little reference to bosh tuyeres. It was known that they were, and are, popular in some European countries and that some continental furnaces had two rows of bosh tuyeres, which were usually termed ' tuyères de secours.' Blast-furnace operators are extremely ignorant about the whole problem of tuyeres and air flow. The location of tuyeres is a purely empirical matter, being governed more by structural reasons than by fundamental scientific reasons.

There is no formula or scientific rule to position the relative levels of hearth tuyeres, slag notch, and taphole. Examination of furnace lines from all over the world indicates wide disparity. Such examination further indicates how the blast-furnace has evolved to its present general shape. It should never be forgotten that the blast-furnace was never designed: it is a product of evolution.

Because bosh tuyeres are simple and inexpensive, and because of the ignorance existing on the subject, in 1954 it was decided to install two rows of bosh tuyeres at *Queen Bess* furnace (*see* Fig. 1). As mentioned, investigations are still taking place into the distribution of air in the hearth and bosh. It is too early yet to be dogmatic about results, but it can be said, after nearly one year's operation, that no harmful effects have as yet been observed.

If it is correct that the use of bosh tuyeres can encourage work in sections of the furnace which are otherwise semi-active, many interesting developments are possible by using two or more rows of bosh tuyeres of varying lengths. Work along these lines is proceeding and it is possible that the future may see a furnace operating with hearth tuyeres 30 in. long and two rows of bosh tuyeres of progressively shorter length.

Much work has been done on the distribution of materials at the top of the furnace. The effects of distribution at the throat are known to be felt at the tuyeres, and it may well be that the converse is also the case. Just as more efficient blast-furnace operation may be obtained by control of distribution of materials (both radially and peripherally), it may also be obtained by radial and vertical distribution of the air.

Blast-furnace Coke

In 1944 much work was proceeding with a view to evaluating coke. Many lines of attack were followed, but today the value of the standard 1½-in. shatter test is regarded as the most important single factor in coke quality.

Much of the increase in iron production which has been obtained over the past years is due to the coke-makers, who have been able to improve the shatter value of the cokes manufactured by The United Steel Companies Ltd. from about 82 to 88–90. Each increase in shatter index has enabled the ironmaker

to lift his operations to a higher level of production.

It has been demonstrated conclusively that the larger the furnace the more important it is to supply coke of high shatter value if all that is possible with a larger furnace is to be obtained.

Throughout the years under discussion intensive efforts were made, and are continuing to be made, by the cokemaker to give the ironmaker a satisfactory fuel. That this has been achieved is clearly demonstrated by the operating results. It is no exaggeration to say that all the benefits which have been obtained by the change to sinter practice, by the use of bosh tuyeres, by bigger furnaces, by harder blowing, etc., would have been of much less avail had coke quality remained at the level obtaining in 1944.

Blast-furnace Refractories

In 1944 the first carbon hearth was built into *Queen Bess* furnace. As each furnace became due for relining carbon hearths were installed. Today, carbon is accepted as the standard refractory for both hearth and bosh construction.

The first carbon bosh was built into No. 5 furnace in 1945. To date, 7,200,000 tons of pig iron have been made on carbon hearths, and 4,600,000 tons of pig iron have been made on carbon boshes.*

No trouble has been encountered either with breakouts or other troubles. Several furnaces have blown a second stack campaign on their original hearths and boshes. When a furnace is blown-out it has, so far, always disclosed the hearth walls and bosh walls virtually untouched.

Carbon in the hearth floor has not prevented the formation of bear or salamander. It is believed that this is because the carbon in service slowly graphitizes, whereupon it becomes soluble in the iron. It is probable that this could be checked and salamander formation prevented by the introduction of undercooling. Much thought has been given to this problem and designs have been prepared. It was decided not to proceed for several reasons. The record of hearth carbon, even though salamanders have not been prevented, is better than the record of ceramics. With furnaces not filled in round the hearth, tapping of the bear is easily accomplished on blowing-out and in no case has the amount of bear been excessive. It cannot be denied that there are certain risks associated with undercooling and it was concluded that the prize to be obtained did not justify the effort. It is felt that carbon will continue to be the standard material for hearth floors.

Apart from solving the problem of hearth breakouts, the use of carbon has permitted considerable enlargement of existing furnaces. Hearth walls 22½ in. thick are standard. Bosh walls as thin as 9 in. have been used with no trouble.

The All-carbon Furnace

When stack scaffolds were a problem it was decided to try carbon refractories in the stack of a blast-furnace, principally because of their non-wetting properties. This story has been told in some detail by Chesters, Elliot, and Mackenzie.[6]

Two all-carbon stacks must be considered as failures. The story of the third is confusing. The following is a brief account of the four furnaces in which carbon was used above the mantle.

No. 6 Furnace

This furnace was completely relined, using carbon brick up to the throat armour:

Blown-in: 4th April, 1949
Blown-out: 22nd April, 1952
Hearth dia.: 18 ft. 3 in.
Total iron made: 292,195 tons.

There was some collapse of lining at the armouring zone in June, 1950, followed by further and more serious collapse in March, 1951. The furnace was operated to blowing-out with no lining at all in the upper 20 ft. Water sprays were fitted. (Demand for iron prevented earlier relining, but this experience gave the operators confidence to try the ' tin-top ' at a later date.) On blowing-out, it was found that virtually no lining remained at all levels higher than 10 ft. above the mantle.

No. 1 Furnace

This furnace was completely relined, using carbon brick up to the throat armour:

Blown-in: 24th October, 1949
Blown-out: 15th October, 1951
Hearth dia.: 18 ft. 0 in.
Total iron made: 176,870 tons.

No trouble with the lining was encountered until May, 1951, when a hot spot developed just below the throat armour. There is ample evidence to show that whatever may have been the initial cause of failure, it was mechanical failure (dislodgment of bricks) which caused the rapid extension of a local hot spot to a large area of total lining collapse in a short time.

No. 5 Furnace

This furnace was completely relined, using carbon bricks up to the throat armour:

Blown-in: 5th April, 1950
Foundation collapse and repair: 26th February, 1951 to 14th May, 1951
Blown-out: 18th January, 1954
Hearth dia.: 18 ft. 3 in.
Total iron made: 373,230 tons.

The story of the campaign is particularly involved and more than a little confusing. For the first 15 weeks the furnace gave excellent operating results. Fifteen weeks after blowing-in, the furnace had a peculiar breakout. This was unusual in that the flow of iron came from a level more than 5 ft. below the tapping hole, whereas all previous breakouts at Appleby-Frodingham had occurred at a level lying within 18 in. of the tapping hole.

No communication was ever found between the breakout and the inside of the furnace. It is believed that the iron went down through the carbon bottom, ran along the layer of refractory cement on which the carbon blocks were laid, and found its way out of the furnace between the carbon-brick joints at the very bottom of the hearth jacket, where cooling is at a minimum. The furnace was off-blast for 38 hr. while the repair was carried out. There is no doubt that

* To 31st May, 1955.

this trouble was caused by movement of the foundations, which was subsequently to cause much more serious trouble.

After this mishap the make and coke rate continued to be good and for the 8-week period up to 3rd March, 1951, the make was 25% above the average of the previous campaign. On this date the furnace suffered a major calamity when the foundations failed and a repair had to be carried out which took 74 days. The furnace had to be emptied and the hearth and bosh demolished, but the stack was allowed to remain, as it was not involved in the repair work.

On examining the blown-out stack it was found that maximum wear had occurred about 15 ft. above the lintel, where the vermiculite bricks used as insulation were exposed. This total loss of carbon covered only a small localized area, about 6 ft. × 5 ft. As vermiculite bricks are incapable of withstanding abrasion, it is confidently believed that the failure was due to air inleakage during the time the furnace was standing before emptying. This view was confirmed when examination disclosed a faulty joint between shell plates in this area. At the furnace top and just above the lintel wear was at a minimum.

A 4½-in. fireclay brick wall was built as a shuttering from the lintel to the armouring zone and this was backed with 60 tons of carbon ramming, between the shuttering bricks and the worn carbon face.

For 2½ years after this repair the furnace gave no more trouble. The makes were consistently high and coke rates satisfactory. As it was intended to discontinue making iron at the North plant in the autumn of 1954, the furnace was blown-out in January, 1954, to make way for the experimental water-cooled steel top described earlier.

No. 4 Furnace

The stack of this furnace was relined but the hearth and bosh linings remained for a second campaign. Carbon bricks were used to a level 29 ft. 6 in. above the mantel:

Blown-in: 3rd February, 1951
Blown-out: 24th February, 1954
Hearth dia.: 18 ft. 0 in.
Total iron made: 312,940 tons.

The furnace was blown-out not because of trouble but because it became redundant with the blowing-in of the new 27-ft. furnace. At this time, the hearth and bosh had worked without trouble for seven years.

The blown-out lining was examined by the staff of the Research and Development Department of The United Steel Companies Ltd. The following extract from their report gives the summary and conclusion of the investigation:

> "*The carbon brick from this stack probably showed the least change in service of any of the furnaces examined after blowing out. This examination, together with those of Nos. 6, 1, and 5 furnaces, confirms that where carbon bricks remain in a blast-furnace stack they are in good condition and in the majority of cases almost unattacked.*
>
> *Furthermore, it appears that for 20 ft. to 30 ft. above the lintel they are capable of withstanding the atmosphere and other conditions within the furnace.*"

At the time of writing, it is felt that carbon is a satisfactory material for blast-furnace linings from the foundations up to and including the lower third of the stack. Above that the evidence is extremely contradictory. As mentioned earlier, the major preoccupation now in regard to refractories is that of finding a satisfactory material for lining the upper two-thirds of the blast-furnace.

Evidence is accumulating that the major cause of stack lining failures may be alkali attack; this has been found to be true in regard to certain installations of carbon in the stack in other works, and it may prove that alkalis have been more destructive of ceramics in the stack than has carbon-monoxide disintegration. This is not proved, but it is the subject of research and experiment. If it should be true, a completely different outlook may be required to solve the problem of refractories for the upper stack.

FURNACE OPERATION AND OPERATING PROBLEMS

As with so many things mentioned in these notes, the last decade has seen a complete reversal of opinion in regard to blast-furnace operation.

Blowing-in practice remains virtually unchanged from that which was set up in 1939. Since then, 34 furnaces have been blown-in at Appleby-Frodingham and on no occasion has trouble been encountered which could be associated with the method of blowing-in.

Blowing-out was the cause of much trouble until the present standard practice was developed. Blowing-out a blast-furnace is one time when all blast-furnace operators are justifiably nervous. The possible hazards are serious. Formerly, most methods of blowing-out involved a progressive lowering of the stockline and the consequent establishment of what could, without exaggeration, be described as a potential explosion chamber. To avoid the formation of this chamber, blowing-out methods have been developed in which the furnace is left full of coke nuts or of iron ore. Coke nuts obviously mean the generation, when quenching water is added, of water gas and the possible ignition of explosive mixtures as the coke nuts are emptied from the furnace. The use of ore leads to slagging and sealing off of burning patches of coke, which are also a possible source of danger.

A blowing-out practice has been developed at Appleby-Frodingham in which the furnace is kept full from the tuyeres to the stockline with quartzite pebbles, screened between 1¼ in. and 2 in. This is a free-flowing and relatively inert material. No water is used until blast is off the furnace.

Because the pebbles constitute a permeable and free-flowing mass, it is possible to use more water and to use it earlier than when blowing-out by other means. Keeping the furnace full ensures only a small explosion chamber in which most of the hazard is eliminated by introducing steam sprays.

Slagging of the pebbles is unusual and the subsequent emptying of the furnace can therefore be carried out rapidly. When the furnace has been cooled down it is possible to empty 500–600 tons of pebbles through a hole cut into the bosh in a matter of minutes.

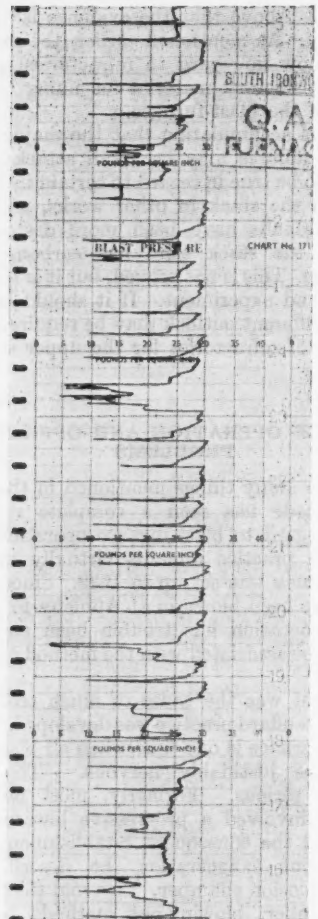


Fig. 8—Typical blast-pressure chart for existing practice at Appleby-Frodingham

Blast Volume and Pressure

In 1944 the operators found it impossible to blow a furnace at more than moderate pressures. The history of ironmaking in North Lincolnshire is filled with examples of hard blowing being tried and achieving nothing. There is no doubt that with ore burdens, velocities in the stock column quite easily reach values at which ore particles are carried upwards so that the voidage in the overlying stock is sealed by these upward-carried particles. For this reason it was always necessary to nurse a furnace to obtain a smoothly descending stock column. Any interruption to even stock descent manifested itself in higher flue-dust losses, higher coke rates, poorer-quality product, and lower production of iron. The last-named was particularly significant: the highest productions were always obtained when the furnace was moving freely.

The author wrote in 1944 (*loc. cit.*,[1] p. 173): "*This nursing of blast volume is a characteristic of the operation and neglect of it always brings trouble in its trend. On furnaces Nos. 9 and 10, 50,000 cu. ft. per minute can be blown with a pressure at the blower of 16 lbs. per square inch. On no single occasion has this volume been possible with the engine pressure at 20 lbs. or 21 lbs. per square inch.*"

Today, these same furnaces are regularly being blown at 30 lb./sq. in., and at this pressure up to 90,000 cu. ft./min. is being blown. The larger furnaces also operate at 30 lb./sq. in., but this is limited only by the capacity of the blower.

Full-scale trials have been carried out during which two blowers together into one furnace have delivered up to 120,000 cu. ft./min. at 32 lb./sq. in. It is believed that with future additions of blowing power, operation at this level will become a regular feature of the practice.

This radical change in blowing practice has only been possible with the change to high sinter burdens. It has also been accompanied by a change in blast temperature; whereas temperatures below 500° C. were formerly the maximum, 750° C. is now carried without trouble.

Stock Descent and Hanging

In 1944 it was said (*loc. cit.*,[1] p. 182): "*Of what may be termed everyday problems, perhaps the most difficult is that of maintaining uniform descent of the stock in the furnace. . . . One thing may be said with certainty—a furnace will not give its best results unless the stock descent is smooth and even.*"

Operating results given earlier indicate that better furnace work is being done now than then. Figure 8 is a reproduction of a typical blast-pressure chart for present practice. It will be seen that the furnace was checked at regular intervals.

No attempt is now made to maintain natural and unassisted descent of the stock column. Rather, it is operating policy to attain stock descent by regular and severe checking. Experience indicates that with high sinter burdens this checking practice gives the following advantages: higher production, lower flue-dust losses, more regular iron quality, and more regular general operation.

At first glance the practice appears to be wasteful, which it is. On the other hand, experience has shown that the air actually blown at the tuyeres, under checking conditions, is greater than could otherwise be the case.

The practice could not perhaps be justified or tolerated when smelting ore burdens, but it is easily justified when smelting sinter burdens. It is believed this change largely arises for the following reasons:

(i) Little, if any, reduction takes place in the upper part of the stack. This section of the furnace is now occupied purely in transferring heat from the ascending gases to the descending charge

(ii) Carbon deposition is much less when sinter is being smelted. This means that the contents of the stack may be regarded as the contents of a bin and the checking may be compared to the mechanical vibration to facilitate the flow of materials through a bin[7]

(iii) The narrow size range of the sinter charged to the stockline, coupled with the fact that sinter does not break down on heating, as does carbonate ore, results in a better size distribution of the charge throughout the furnace

(iv) It must be remembered that sintering does not lead to a reduction in slag volume, so that Appleby-Frodingham furnaces are still making 26 cwt. of slag per ton of pig iron produced. The more smoothly the furnace is operating, as measured by stock descent, the more slag is held in suspense in the bosh and in the lower stack. Slipping or interruptions to stock descent therefore usually meant the sudden descent of comparatively cold viscous bosh slags into the hearth of the furnace. Routine checking at frequent intervals ensures that a minimum of such slag is held above the tuyeres so that slips, if they do occur, cannot precipitate an undue amount of cold material.

In the early days of high-sinter practice, before routine checking was adopted, a serious operational trouble was the violent slipping which frequently occurred. Slips of this nature have on occasion led to an almost instantaneous stoppage of the gas blowing engines. Since routine heavy checking was introduced, slips of this violence are unknown.

With ore burdens, and when attempting to maintain uniform stock descent, trouble is frequently encountered because of incorrect peripheral distribution. With checking practice peripheral distribution, as indicated by inwall temperatures, is much more consistent than was formerly the case. It is still believed that the pursuit of stock descent with an ore burden was justified. It is believed with equal confidence that checking practice with a sinter burden is justified.

Rice[7] proposed a rating factor for blast-furnace operation based on tons of coke burnt per day under conditions of average coke consumption. On ore practice it has never been possible, even with specially prepared ore burdens, to achieve anything like 100% Rice rating. The combination of sinter burdens, hard blowing, and routine checking has enabled this goal to be attained; 95% Rice is achieved regularly and more than 100% has been achieved on occasions. It is believed, with some confidence, that the provision of more blowing power in the future will permit operation of the furnaces at even higher pressures and the attainment of more than 100% Rice as a routine.

Stock Distribution

Stock distribution is still of importance. It will always be of importance so long as iron is made from

Table IV

HEAT BALANCES OF COMPARATIVE PRACTICES

	35% Sinter		97% Sinter	
	B.t.u.	%	B.t.u.	%
HEAT GENERATED				
From gasification of C to CO	6,880,000	46·1	5,020,000	38·8
From gasification of C to CO_2	5,980,000	40·0	5,650,000	43·6
Heat from hot blast	2,070,000	13·9	2,280,000	17·6
Total heat input	14,930,000		12,950,000	
HEAT EXPENDED				
For Metal				
Reduction of iron oxides, etc.	6,920,000		6,746,000	
Decomposition of calcium phosphate	163,000		149,000	
Sensible heat for iron	1,106,000		1,106,000	
Total for iron	8,189,000	58·0	8,001,000	65·2
Total for slag (sensible heat)	1,925,000	13·7	2,065,000	16·9
For Evolution of Volatile Matter				
Evolution of CO_2 from burden	657,000		229,000	
Evolution of combined water from burden	424,000		11,000	
Water dissociated to make up H_2 in gas	969,000		286,000	
Heat required for moisture in gas	194,000		48,200	
Total for volatiles	2,244,000	15·9	574,200	4·7
Sensible heat of dry gas	1,345,000	9·6	1,390,000	11·3
Decomposition of blast moisture	397,000	2·8	234,000	1·9
Total heat expended	14,100,000	100·0	12,264,200	100·0
Total heat generated (as above)	14,930,000		12,950,000	
Balance (heat loss by radiation, etc.)	830,000		685,800	

coke and ferruginous raw material in a blast-furnace.

With the former ore practice, good furnace results were never obtained when ore was charged on the bell first. Many years' experience has shown that this practice gave a lower coke consumption but a very much lower rate of production. Today, sinter on the bell first is a regular method of charging. The difference probably arises from the fact that sinter is of a closer and generally smaller size range and has no shrinkage resulting from the loss of volatiles in the top few feet of the furnace. Generally, present practice confirms that it is not good practice to maintain the same charging method uninterruptedly. Deliberate changes in charging method are effected on a routine basis.

Utilization of Fuel

Heat balances have been prepared for two typical months' operation: one at 33% of sinter and the other at virtually 100% of sinter. The results are given in Table IV. It is suggested that these are worthy of close study because in them lies the justification for high-sinter practice. The amount of heat (and therefore coke) necessary to deal with the volatile content of the ore burden is an appreciable percentage of the coke consumption of the furnace. Once the evolution of volatiles is performed more efficiently outside the furnace, the tonnage of coke formerly used for that purpose is free to perform its many functions in making pig iron.

Carbon used in the sinter plant is burnt wholly to CO_2, whereas in the blast-furnace it is burnt to a mixture of CO and CO_2.

Relining

The constant demand for iron production during the past decade, together with the concentration of production into a smaller number of units and the increasing capital cost of the plant involved, led to the necessity of developing means of rapid repair and relining. Some success has been achieved which has been described elsewhere.[8] It is an important aspect of ironmaking and it is now accepted as such.

Weather

For many years ironmaking results in winter have been poorer than in summer. Trial and research proved that heavy rainfall without rapid evaporation led to a deterioration in furnace performance. This arose not only from the increased amount of water charged to the furnace, but also from the much poorer screening efficiency resulting when wet carbonate ores are screened by commercial methods.

Because of the nature of the ore fines adhering to the oversize, these fines separated on entry to the blast-furnace. Every spell of wet weather led to trouble at the furnaces. Performance above average was never established in winter.

The position has completely altered when using sinter burdens. Obviously, the physical quality of sinter is not affected by atmospheric conditions. This is a very important and valuable factor in the use of sinter burdens. Operation is now maintained at a much more uniform level throughout the year and spells of severe weather no longer have repercussions on ironmaking and consequently on steelmaking.

CONCLUSION

The last decade has seen serious deterioration in coking coals and Frodingham and Northampton iron ores. Sulphur in coking coal has increased as it has in iron ore. The iron content of the ores has decreased and the amount of ferrous iron has increased. All these things add to the difficulties of economically making pig iron from these raw materials. The paper briefly mentions some of the means which have been employed to meet the situation.

Ironmaking at Appleby-Frodingham is now firmly established on the basis of carrying burden preparation to its logical limit and charging to the blast-furnace high-quality coke and virtually nothing but sinter. It is not suggested that no problems remain. It has been truly said that the solution of one problem is the formulation of another. The problems associated with smelting are, in the main, quite different from the problems associated with smelting British carbonate ores.

Acknowledgments

The author of these notes is very conscious that the work described in the preceding pages has been that of very many people. Without the constant help and support of their engineering and research colleagues, the production staff of the ironworks realize that the progress described would have been impossible.

Especially during the more difficult and anxious days (and they were not infrequent), the ironworks staff received constant encouragement from Mr. Gerald Steel (General Managing Director of The United Steel Companies Ltd.), from Lt. Cmdr. G. W. Wells (General Manager of the Appleby-Frodingham Steel Company), and from Mr. F. H. Saniter (Director of Research, United Steel Companies Ltd.). Finally, the author wishes to express to the ironworks staff of Appleby-Frodingham his deep gratitude for their loyal and unselfish work over many difficult and exciting years.

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The Expansion Scheme of John Lysaght's Scunthorpe Works, Ltd.

By W. L. James, J.P.

SYNOPSIS

The paper deals in broad outline with the modernization and expansion of John Lysaght's Scunthorpe Works, Ltd., a scheme involving an expenditure of £10½ millions; this work was carried out in all departments in such a way as to ensure that the maximum possible iron and steel production was maintained.

The project involved the replacement of coke ovens, the installation of a new blast-furnace and the modernization of existing units, an increase in the size of open-hearth units, and the provision of new soaking pits, a new rolling mill, a wire-rod mill, and all necessary ancillary services.

Targets were fixed for subsequent production rates, which have since been achieved and exceeded. 1196

HISTORICAL SURVEY

THE NORMANBY PARK STEEL WORKS were opened in 1912 with the object of producing 2500 tons of ingots per week, to be rolled down into sheet bar. The works then comprised a coal washery plant, a battery of 96 Semet–Solvay coke ovens, three blast-furnaces, one mixer, four open-hearth steel furnaces, and a 36-in. reversing cogging mill feeding a 32-in. two-high steam-driven reversing finishing mill. The mill was served originally by six coal-fired soaking pits; four gas-fired pits of the regenerative type were added in 1917, and the coal-fired pits were subsequently redesigned and converted to gas firing.

Two more blast-furnaces were added in 1917 and 1922, respectively, and in 1932 a battery of 47 Becker-type coke ovens replaced the old Semet–Solvay plant. A further battery of 23 Becker ovens went into use in 1937. A Greenawalt sinter plant was added in 1938, and additional open-hearth furnaces in 1917, 1918, 1924, 1930, and 1951. Waste-heat boilers were provided in 1931, and No. 2 mixer was added in 1934.

Whilst the steel furnaces were nominally of 45 tons capacity, the bath area was increased in 1923 to 60 tons capacity. In 1946 furnaces *A*, *G*, *H*, and *T* were increased from 60 to 120 tons capacity, using bifurcated launders.

Thus at the end of the second World War, the works comprised one crusher and screening plant, a three-pan Greenawalt sintering plant, one battery of 47 and one battery of 23 Becker coke ovens (with by-product plant), five blast-furnaces, and eight open-hearth furnaces (six of 60 tons capacity and two of 120 tons capacity), together with two active hot-metal mixers. The teeming pit, serviced by a narrow-gauge railway system to the soaking pits, and the mill were unchanged. The blowing plant consisted of gas engines, to which two steam turbo-blowers had been added in 1925 and 1932, respectively. The works steam pressure was 160 lb./sq. in.

POST-WAR EXPANSION

Naturally, after the War the replacement of old plant and expansion of the production departments to give larger outputs was soon under discussion, in which the author joined in April, 1948.

The average weekly outputs of coke, iron, ingots, and rolled steel at this time were:

	Tons
Coke	5999
Pig iron	4659
Ingots	6062
Rolled steel	4998

It was finally agreed that the new average weekly outputs were to be

Iron (using 3 furnaces)	7200 tons
Steel ingots	10,500 ,,
Rolling mill	10,500 tons of ingots

It was decided to transfer the rod mill from Cardiff to Scunthorpe, to produce 3200 tons of wire rods.

The cost of the whole scheme was estimated at £10½ millions, and the scheme was completed within this financial structure.

To bring about these results meant in effect the complete replacement of the rolling mills and a large remodelling and rebuilding scheme in every department of the works, as follows:

Raw Materials

A new method of handling and stocking of ores, a new method of cooling and handling sinter, and the replacement of the old method of steam engines, wagons, and tippers on the blast-furnace bunkers by a belt system.

Coke Ovens

The existing batteries (No. 1 of 47 and No. 2 of 23 ovens) were 16 years and 11 years old, respectively, by 1948. It was necessary therefore to plan not only for the increased coke requirements but for also the replacement of these units.

Nos. 3 and 4 batteries, each of 23 new Woodall–Duckham ovens, and a new quenching station were put in hand as part of the scheme, the replacement of Nos. 1 and 2 batteries being left to a later date.

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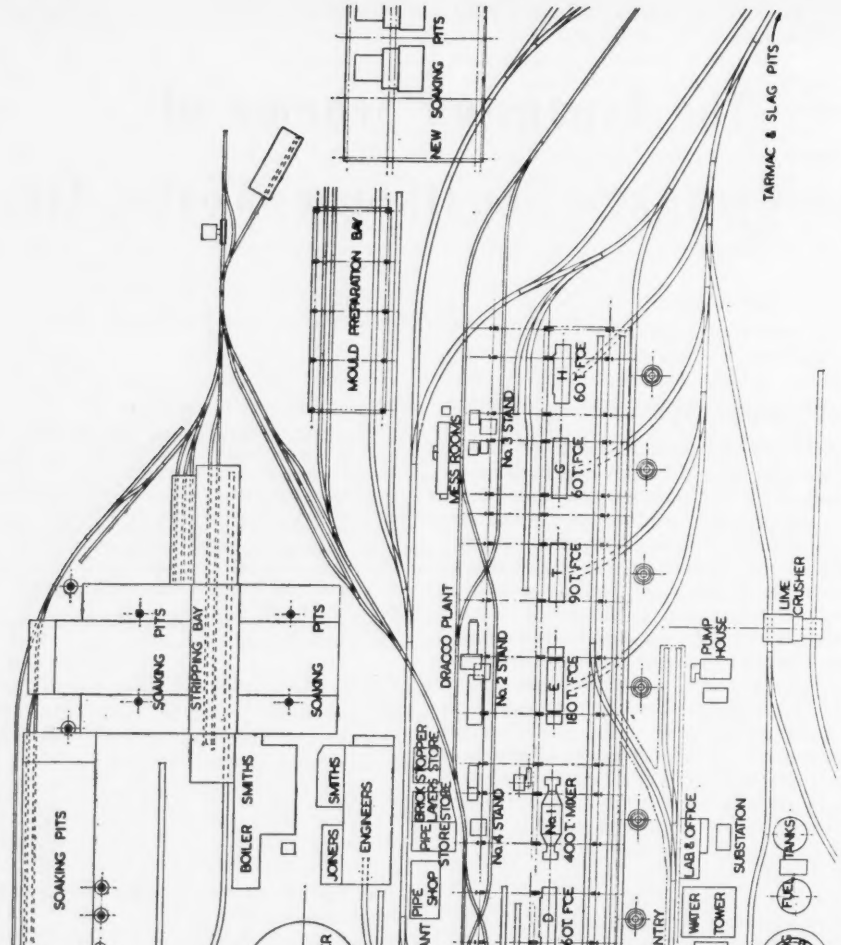

Fig. 1—Melting shop : layout of existing plant

Blast-Furnaces

One new furnace (22 ft. 6 in. hearth dia.) with new bunkers, stoves, blowers, etc.

Rebuilding No. 4 furnace.

Complete replacement of the old gas-cleaning system by a Lodge–Cottrell electrostatic plant.

Increasing the capacity of the pig casting machine and provision of an adequate stocking ground for pig iron.

Open-Hearth Plant

The complete replacement of the pitside building and the valley, columns, and girders, to give a new pitside of 70 ft. instead of 54 ft. 6 in. and to lift the roof 5 ft.

To erect three electric overhead travelling cranes of 175 tons capacity, to replace the existing 75-ton cranes, and to take down the latter.

To replace all steel ladles by 120-ton units, and to replace the entire railway system of the pitside and the ingot handling traffic by a wide-gauge railway.

To pull down and replace all teeming stages, lead-fume extracting plant, ladle handling plant, and stopper houses.

To strip the roof, roof trusses, and purlins, re-erect the latter, and re-roof the whole of the furnace stage.

To extend the open-hearth building at the south end by 116 ft., increase the height by 6 ft., and erect a new 120-ton fixed open-hearth furnace.

To rebuild and enlarge furnaces *B*, *C*, and *D* to a similar capacity (120 tons).

To build a new ramp and gantry to the south for the scrap bogies, new scrap shed, and Gellivare ore bank, to replace those already in existence at the opposite end of the works, and to remove the old slag plant of Tarmac, Ltd., and rebuild on a new site.

To clear the whole of the engineering shops, clustered in the centre of the works, and re-site them in order to install the new stripper bay and ingot mould shop.

Mills

To build the new cogging and billet mills, together with the soaking pits, and train and transfer the mill crews.

To prepare and install foundations and a mill building for the rod mill, then at the Cardiff Works of Guest, Keen and Nettlefolds Ltd.

To re-design and replace the entire steam and power plant, in addition to remodelling the whole cooling-water system and installing new cooling towers at various points in the works.

The whole scheme was of the order of a ' green field ' conception, but unfortunately there was no green field site available, and so the whole project had to be carried out so far as possible without interfering with maximum production. The layout of the existing plant is shown in Fig. 1.

Traffic System

In an expansion scheme of this magnitude the most important factor is an efficient traffic system, and this was the first consideration in preparing the various development plans.

The aim was to reorganize the works traffic system so as to isolate the traffic to the open-hearth furnaces, the ingot handling traffic, and the mill traffic from the general works traffic.

At this time the steel furnaces required two locomotives per shift, with occasional additional assistance from a third locomotive. The ingot traffic absorbed three steam locomotives on a special narrow-gauge railway system, and the rolling mill was served by a further two steam locomotives at the finishing end.

Today one Diesel locomotive per shift serves the open-hearth shop with scrap, Gellivare ore, etc. One Diesel per shift handles the ingot traffic, weighing, stripping, and setting of ingots at the soaking pits, and also the mould-shop traffic for cooling, changing, and cleaning of moulds. A further Diesel handles the traffic from the rolling mill. All these machines are 204-h.p. straight Diesel locomotives.

No. 1 Blast-furnace and Rolling Mill

Although the new plans would inevitably cause interference or obstruction in every department, the No. 1 blast-furnace scheme and that for the rolling mills probably offered the least potential trouble.

Work therefore began on the site of the old No. 1 furnace, now demolished, for the foundations of the new No. 1 blast-furnace and its ancillaries, and on the soaking pits and the rolling-mill site at the south end of the works.

Work also began on the site for the bunkers for the new blast-furnace, and on the foundations of the steel structure to carry the belts for ore handling to the blast-furnace bunkers generally.

The building of the new No. 3 coke-oven battery was proceeding but before work could begin on No. 4 battery the old scrap shed had to be dismantled and the Gellivare ore bank transferred from the north end of the works to the new site at the south end.

Melting Shop

Experiments in 1948 established beyond doubt that the ingot target of 10,500 tons could be achieved by the addition of one extra fixed furnace of 120 tons capacity, but the problem of remodelling the open-hearth building was the subject of much debate and consideration.

Before the final scheme was approved all the men who were to carry any responsibility for production in the new shop, including all the foremen, had the scheme explained to them in detail and were asked for their views on all matters of detail.

Finally, a small wooden model of the old pitside, with replaceable sections to show the new developments, was produced, and a representative body of all the grades of labour concerned met the management and had the scheme and the method of carrying it out explained to them, using the model for demonstration purposes. It was pointed out that for about eighteen months they would work under uncomfortable conditions, acutely so at times, but that their help was essential, and it is a source of pride to the management that they gave that help and co-operation which is the basis of all good teamwork.

This method of detailed discussion followed by talks with the men and their representatives was carried out in every department, and it is certain that this policy helped enormously in the difficult circumstances which eventually arose.

Finally it was decided to carry out the reconstruction work in the open-hearth plant in three stages, and, by so doing, ensure the least interference with production. Figure 2 shows the stages of reconstruction.

Stage I

Stage I comprised pulling down the building structure over furnace *H* at the south end of the shop and demolishing and rebuilding it, and extending the whole shop by 116 ft. in order to house the new

furnace *J*. In addition, it was necessary to build and place in position one 175-ton electric overhead ladle crane on the new structure to service the two new open-hearth furnaces *J* and *H*, each of 120 tons capacity, and to erect a new static teeming platform for uphill teeming of lead-bearing steels, together with a new fume extraction plant.

Provision had also to be made for handling steel teeming ladles of the new 120-ton type for the new furnaces; eventually a ladle shop was to be built to service all the furnaces.

This section was to be serviced by a broad-gauge railroad system, but the last of the old plant covered by stage III had a narrow-gauge railroad; since both parts would eventually work together for a time, it was therefore necessary to cover both types of traffic, and so a combined three-rail system was laid down between the stripping and soaking pit bays.

As the blast-furnace slag traffic to the existing Tarmac plant had to pass through this new area, it was found impossible to use a Scotch derrick crane; it was therefore decided to use stationary guy derricks, with guys attached to weighted winches and also to steam cranes.

The positioning of the guys so as to ensure that normal traffic was not interrupted was a difficult problem at all times, and as all heavy columns and girders were brought in as required on 40-ton wagons, a close liaison with the production departments was very necessary. Care was taken that these heavy loads were moved as slowly as possible to avoid dangers arising from vibration and of derailments.

The installation of the first 175-ton crane was achieved by bringing the main girders of the cranes to the shop in three sections, and sitting them upon packing by steam crane. After lining up and checking, they were riveted. In the meantime the end carriages had been brought in: these were erected and lashed to the building as a precaution until the main girders were ready. Then the crane girders were brought into position, winched up, and fixed to the end carriages.

Summary, Stage I—The erection of building columns in this section began in January, 1950, the gantry and roof girders in February, 1950, and the 175-ton crane by September, 1950, and both furnaces *H* and *J* were in use by the end of June, 1951.

Stage II

This stage involved the north end of the open-hearth shop: furnaces *A*, *B*, *C*, and *D*, and No. 2 mixer.

It was decided that all dismantling and re-erection would be carried out by steam derrick cranes on bogies, except where heavy girder and column work was concerned; these would be handled by stationary guy derricks which could be moved rapidly from position to position by the steam derricks.

The congestion of traffic at the north end, in the narrow space between the blast-furnace and the open-hearth plants, did not leave sufficient space available to erect the first derrick crane quickly enough. To overcome this difficulty the derrick crane was erected outside the pitside building, on the east side, and by this means the first 100 ft. of the casting bay, plus the gable end of the building, were removed.

The second derrick crane was then erected inside the building, and dismantling proceeded. Meanwhile, the first derrick crane was dismantled and re-erected in the casting bay, using the second derrick crane for the purpose, and dismantling continued.

As the valley columns and girders between the casting pit and the charging stage were being rebuilt, it was necessary to dismantle the roof over the charging stage. This was done by using a guy derrick and stacking the roof trusses and purlins on the floor of the stage.

By means of temporary gantry girders to bridge the gap between the old and new structure on the charging stage it was possible to transfer a charger crane to help in rebuilding No. 2 mixer, and furnaces *A* and *B*, and these were at work in March, 1952, using a temporary static teeming stage until the first of the mechanical teeming stands should be completed.

Summary, Stage II—Dismantling began in September, 1951, and the sheeting of charging and casting bays in November, 1951; the second 175-ton electric overhead casting crane was ready in December, 1951, and the third in January, 1952. One of the old 75-ton cranes was taken down in December, 1952, and No. 2

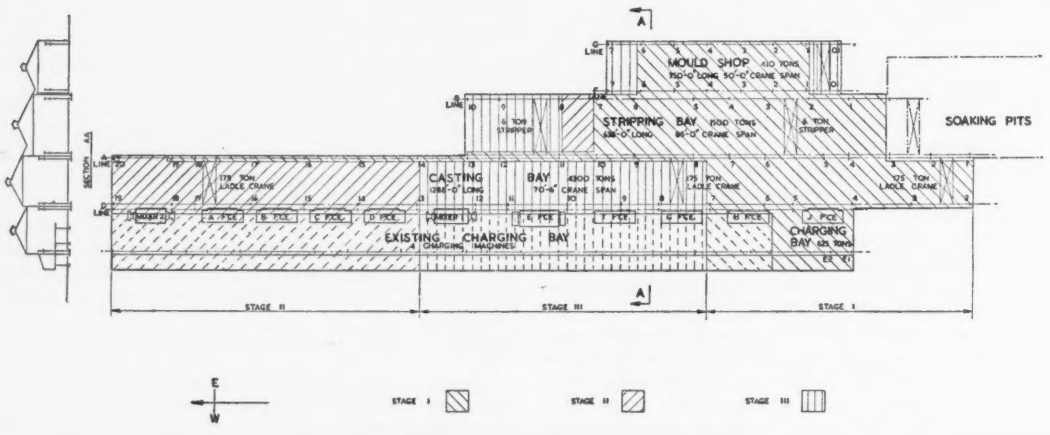

Fig. 2—Stages in extension and reconstruction

mixer and furnaces *A* and *B* were in production in March, 1952. Stage II was completed in June, 1952.

Stage III

The work was by now much more straightforward by the time stage III was reached: No. 1 mixer, and furnaces *E*, *T*, and *G* were all taken off, and the dismantling continued; it was possible to pull out the old narrow-gauge railroad, and the broad-gauge system was completed. The remaining two 75-ton electric overhead cranes were removed.

During this time the parallel building of the stripper bay was completed, and also the mould shop and hot-metal weighbridge foundations. Figure 3 shows the layout of the plant at the end of stage III.

Summary, Stage III—Dismantling began in March, 1952. The 175-ton electric overhead cranes were traversing the full length of the new building in June, 1952, and No. 1 mixer and all the furnaces were in production in October, 1952.

The average weekly output of ingots for the year was 6470 tons, and the average weekly output through the three stages of reconstruction was:

Stage I	6894 tons
,, II	5944 tons
,, III	7259 tons

Table I gives detailed information about weights of materials handled in connection with this job.

Reorganization of Rolling Mill Practice

From 1948 to 1950 work was proceeding on the mill site and on that of the No. 1 blast-furnace. By

Table I

SUMMARY OF WORK CARRIED OUT

Section of Work Involved	Detail	Stage I (5.4.51–21.6.51)	Stage II (18.9.51–7.6.52)	Stage III (7.6.52–9.10.52)	Total, Stages I, II, and III
Excavation	Column foundations, cu. yd.	4934	495	335	
	Furnace *J* foundations, cu. yd.	4281	...	...	
	Furnace platform foundations, cu. yd.	45	104	91	14,184
	Ancillary plant foundations, cu. yd.	471	580	1082	
Drainage	Trench, cu. yd.	952	447	367	
	Length and size of drains, yd.: 6 in.	223	356	476	1055
	9 in.	192	62	33	287
	12 in.	347	78	...	425
Concrete	Column foundations, cu. yd.	3861	373	279	
	Furnace *J* foundations, cu. yd.	2021	...	...	8081
	Furnace platform foundations, cu. yd.	39	92	71	
	Ancillary plant foundations, cu. yd.	345	344	656	
Steelwork and corrugated sheets	Tonnage dismantled	554	1360	1299	3213
	Tonnage erected	4563	1408	1353	7324
	3 × 175-ton ladle cranes	215	430	...	645
	2 × 6-ton ingot strippers	259	...	...	259
Railtracks laid	Permanent broad-gauge track, yd.	466	697	1800	
	Temporary broad-gauge track, yd.	1055	1827	583	7355 (4·17 miles)
	Temporary two-gauge track (soakers), yd.	83	...	...	
	Temporary narrow-gauge track, yd.	737	107	...	
	Permanent broad-gauge crossings	6	12	36	
	Temporary broad-gauge crossings	13	12	...	94
	Temporary narrow-gauge crossings	13	2	...	
	Permanent broad-gauge dia. crossings	2	1	...	
	Temporary broad-gauge dia. crossings	...	3	...	10
	Temporary broad- and narrow-gauge dia. crossings	4	...	...	
Railtracks pulled out	Existing broad-gauge track, yd.	417	630	200	
	Temporary broad-gauge track, yd.	650	1517	1381	7228 (4·11 miles)
	Existing narrow-gauge track, yd.	330	2103		
	Existing broad-gauge crossings	4	8	3	
	Temporary broad-gauge crossings	5	8	3	55
	Existing narrow-gauge crossings	3	21	...	
	Temporary broad-gauge dia. crossings	...	...	3	8
	Existing narrow-gauge dia. crossings	1	4	...	

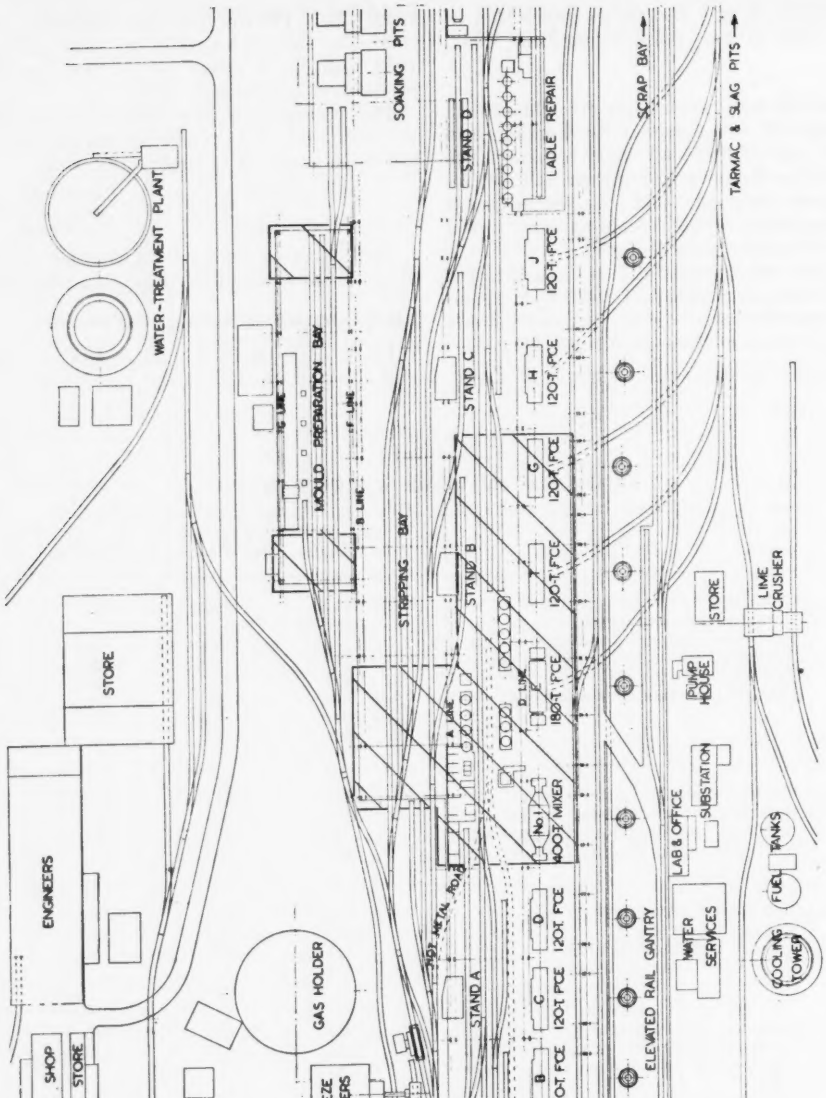

Fig. 3—Layout of plant : stage III

January, 1950, the mill was rapidly nearing completion, so that the selection of the men for manning the various jobs in the new mill had to be considered, as well as their training for the new jobs.

During the construction period the mill management operated a scheme whereby all the mill operatives paid frequent visits, under their guidance, to the mill so that they would become familiar with all the details of the soaking pits, cogging mill, and continuous billet mill while building was going on; the wisdom of this course was soon evident when production began.

When the cogging mill controls were installed and completed, the selected crew members were taken over to work and thus familiarize themselves with the controls they would eventually use. The use of timber baulks for practice in turning up with the manipulators was introduced with very useful results, but this necessary training time was all too short.

Training of a different kind was also taking place amongst the billet mill crews. Two staff engineers, both expert modelmakers, produced a scale model of a Morgan housing which was used to demonstrate roll changing and adjustment and guide setting, and in this way a thorough working knowledge of such a housing was easily acquired.

Later, when erection of the billet mill was complete, the crews were exercised by roll changing and guide setting on the mill housings themselves, but here again pressure of circumstances and anxiety to get the new mill to work reduced the training time seriously.

Another part of the mill which had occupied the electrical engineers from the first was the electric flying shear, at this time the only one of its size in the world. The importance attached to this machine was such that two U.S. engineers came over specially to install it and guarantee its working. They found on their arrival, much to their astonishment and admiration, that the installation of the complex piece of machinery had been completed accurately by the works engineers.

The twelve new one-way-fired recuperative soaking pits were lit up on completion and given very rigorous tests, to ensure their efficiency. From the ingots charged for test purposes an ingot was occasionally cogged down to 5 in. × 5 in. square billets so as to give the cogging crews a little practice before general production began.

The next step was to test the Morgan mill and the electric flying shear with hot steel, and a series of test periods were run for this purpose. Since everyone by this time had gained a little experience, and since the time factor was important, it was decided that further training must come from actual production because it was vital to get the new mill going as soon as possible, because the old mill site was needed for the new engineering shops and the existing shops were in the way of the open-hearth plant reconstruction. It was therefore decided that production should begin in the new mill on one shift on 5th June, 1950, and that two shifts should continue in the old mill.

After three weeks the second shift was started; finally the mill went on to three shifts on 13th August, 1950, and the old mill was closed down.

Once three-shift production had begun the mill crews had to face the normal mill programme of steels ranging from dead soft, leaded, free-cutting, high-carbons, and all ranges of silicon and 'Crystalloy,' to Stalloy and stainless. Although their progress was very steady, it was, not unnaturally, slow; in the first production week on one-shift basis 1460 tons of ingots was rolled, and sheet bar (Stalloy quality) 12 in. × ½ in. at 10 lb./ft. was successfully produced. The first two-shift week's rolling totalled 2700 tons of ingots, and on the three-shift basis 5700 tons of ingots was rolled in the first week.

By December, 1950, the weekly average of ingots rolled was 7430 tons. A year later 10,000 tons was exceeded for the first time, and the weekly average for November, 1952, was in excess of the target figure of 10,500 tons, just over two years after the first bar was rolled.

Ingot Stripping

Probably the greatest production problem encountered during this time was that of ingot stripping. Unfortunately the delivery of the new stripping cranes had been delayed; as rolling had begun in the new mill it was necessary to accept and use such facilities as were available, and so it was decided to move the old hydraulic stripper into a position in the new stripping bay; accordingly the foundations and all pipework were prepared at the new site, and then the stripper was transferred one weekend. As this machine had been erected in 1912 to handle 2-ton ingot moulds, dealing with 4-ton moulds was not easy and presented some anxious moments. The stripper was kept in operation successfully by the use of steam cranes, and with some tedious back-shunting it was possible to use the stripper cranes remaining in the old mill soaking-pit building.

Blast-Furnace Operation

At the blast-furnace site, the erection of No. 1 furnace and the new gas-cleaning system and the installation of the ore bunkers and belt-feed system for the furnace were nearing completion by the end of July, 1951, and it was decided that the furnace would be ready to blow-in in early September. Actually, the new No. 1 blast-furnace was blown-in on 10th September, 1951, but it was shut down by a breakout near the south-side slag notch on 15th September, 1951.

This mishap to a new furnace in its first week was naturally a great disappointment, but by working round the clock the necessary repairs were completed in six days; production was resumed on 21st September, 1951, and the furnace went away very easily.

The second breakout, which occurred on 6th October, was expected, and repairs were effected in 4½ days; the furnace went into production again by 11th October, and there was no difficulty in blowing-in.

Since that time the furnace has worked very well, and is averaging in excess of the target figure of 3200 tons weekly.

With No. 1 furnace in blast it was possible to test the belt feeds and trippers on the bunker system of the new unit, but in order to feed the bunkers of the old furnaces from the belt system, ore and coke chutes

had to be installed on that part of the bunkers where the locomotives and the ore tippers were working.

The problem here was that before the chutes could be tested they had to be installed, and once they were in position it was impossible to use the locomotive and wagons. In other words, whilst it was possible to install one chute and carry out tests, the decision had to be made at the conclusion of the tests when to carry out the whole installation and cut out the locomotives and wagons; from then on the scheme had to work, otherwise the output of the smaller furnaces would suffer through any inability to fill their bunkers.

It was decided to take the risk of this final step, and since that date the bunkers have been fed by the new system; although at first, as might be expected, many troubles had to be dealt with, the blast-furnace output was not affected.

The completion of the belt-feed system to the blast-furnace bunkers made it possible to remove the bunker railroad and demolish the cupola, for which there was no further need.

In order to bring this site clearance about, a new gantry had to be built for tipping Gellivare ore, parallel to the new scrap shed; the dump of 20,000 tons of ore had then to be transferred from the blast-furnaces at the north end of the works to the new dumps, with, in addition, 40,000 tons of rubble.

No. 4 Blast-furnace

As mentioned earlier in the paper, one of the items in the scheme was the rebuilding of No. 4 blast-furnace. This furnace lacked sufficient height, and as a result iron quality was difficult to control and flue dust losses were heavy; although it worked rapidly enough, the coke consumption was, as might be expected, too high.

As both the open-hearth plant and the rolling mills were demanding more output, the demand for iron production was at a maximum, and so it was essential that No. 4 furnace should be out of production for as short a time as possible.

There were at this time five blast-furnaces in production:

No. 1	22	ft.	6	in.	hearth dia.
No. 2	12	,,	0	,,	,, ,,
No. 3	13	,,	6	,,	,, ,,
No. 4	18	,,	0	,,	,, ,,
No. 5	18	,,	0	,,	,, ,,

The required output of 7200 tons of iron was possible from Nos. 1, 2, 3, and 5 furnaces, but Nos. 2 and 3 were approaching the time when the question of reconstructing one or both would arise. The problem was whether this 6 ft. of extra height could be added to the furnace without having to demolish and rebuild it completely.

After a number of possible schemes had been considered carefully it was eventually decided to set up an **A** frame, to carry the bucket-hoist structure, and then cut it loose from the furnace shell. The downcomer to the dustcatcher would also be cut, to release the furnace shell. Next a suitable stiffening steel structure would be welded inside and on to the shell. After this the furnace shell would be cut at the lintel plate and the whole shell raised by hydraulic jacks under the internal supporting structure to the required height, the new shell plates being welded in the gap opened between the lintel plate and the bottom of the raised shell.

It was fortunate that during the lifting process the weather was calm; it was a great relief when the welding was completed.

The increased height of the furnace top necessitated fitting a new swan-neck section into the bucket-hoist structure, and this in turn required a slight alteration to be made to the bucket crab to enable it to ride up and over the slight curve in the swan neck.

The furnace was blown-out on 10th July, 1952, and, after stripping the lining and removal of the bear, work began on the shell. The furnace was handed back again for relining on 6th March, 1953. The relining was completed by 15th April, 1953, and the furnace was blown-in again on 17th July, 1953.

Since this operation was completed, No. 2 furnace has been blown-out and pulled down, and No. 3 furnace has been demolished and rebuilt on new foundations to give an 18-ft. hearth diameter.

The blast-furnace plant now consists of Nos. 1, 3, 4, and 5 furnaces; normally No. 1 and any two of the smaller furnaces will be worked at one time.

Scrap Shed and Railroads

The completion of the new scrap shed in July, 1951, had made it possible to demolish the old scrap shed and so liberate the area required for the new battery of coke ovens (No. 4), together with a new coal bunker and quenching station. This meant that a start could be made on lifting and relaying the whole of the railroad system in this area.

This work had to be carried out to a plan because much of the work had to be done at times which interfered least with the mineral traffic to the coke ovens and ore handling plant, and also to locomotives engaged in the blast-furnace slag traffic.

Gas Cleaning Plant

The erection of the new Lodge–Cottrell electrostatic gas-cleaning plant had gone on side by side with that of No. 1 blast-furnace. The next step was to connect the older furnaces with it by means of new gas mains, and then demolish the whole of the existing Thyssen gas-cleaning plant and the old mains. This was successfully accomplished by April, 1951.

Steam and Power Scheme

With the completion of the major schemes development of the new steam and power scheme could begin. The only part of it which had been attempted up to then was the installation of the large Brown Boveri turbo-blower (65,000 cu. ft./min. at 18 lb./sq. in.) for blowing the large No. 1 blast-furnace. This was, of course, a case of necessity, and the blower was driven from the existing system. This blower worked continuously for 20 months; during this time full advantage was taken of normal furnace stoppages to carry out essential inspection and maintenance.

The decision to replace steam-driven rolling mills by electric drives meant that the demand for electrical power would be substantially increased. The electrical generating plant consisted of three mixed-pressure turbo-alternators, each of 2500 kW. rating, and four gas-engine-driven generators, having a total capacity

of just over 3000 kW. A number of rotary converters had been installed to supply the large D.C. load on which the works then operated. A supply of power from the National Grid system existed, but the switching arrangements did not permit much flexibility.

The steam-raising plant consisted of a large number of small units, all burning gaseous fuel, with two units arranged to be fired with coke breeze in case of gas shortage. The steam supply at 160 lb./sq. in. at 480° F. was common throughout the works.

It was very necessary, therefore, in the new scheme to develop the maximum use of surplus gases in the interest of fuel economy and the national coal shortage.

It was decided that the development of the steam plant must be controlled by the following factors:

(i) The utilization of steam raised must produce the maximum generation of electricity without increasing the total steam required
(ii) The cost of steam raising by the new plant must be the lowest possible
(iii) The reliability of the new plant must be high in order to meet the exacting demands and conditions of an iron and steelworks.

The factors deciding the type of boiler to be installed were:

(*a*) The fuel and water available
(*b*) The load factor
(*c*) The site available for development.

Emphasis was laid on the fact that the works had been developed as a balanced unit as far as surplus gas was concerned, and gas balance was all-important in any new scheme.

The scheme was based on having 3,000,000 cu. ft. of blast-furnace gas per hour for steam-raising purposes. It was finally decided that the new plant should provide for 160,000 lb./hr. to be available at all times, and so the plant installed was as follows:

(i) Three 80,000-lb./hr. gas-fired water-tube boilers, operating at 625 lb./sq. in. at 800° F.
(ii) Two 5000-kW. back-pressure units taking steam from the boilers and exhausting into the existing works system at 160 lb./sq. in. and 535° F. at full load
(iii) Two sets of reducing valves with desuperheaters to operate within the same high and low steam conditions as the turbines
(iv) Duplicated feed heating and de-aerating systems with feed pumps, the system being designed for 210,000 lb./hr.
(v) A water-treatment plant for low-pressure boiler feed treatment
(vi) Two turbo-blowers for servicing No. 1 blast-furnace
(vii) The replacement of all rotary converters, the D.C. supply being de-centralized and fed from mercury-arc rectifiers.

The construction of the new boiler plant began in May, 1952, and all three boilers were commissioned by July, 1953, steam being supplied to the low-pressure system through the reducing valves. In the following month (August) the first back-pressure turbo-alternator was put on load, and the second followed in December, 1953. The total power generated under the new system is 8900 kW., as against 3200 kW. on the old plant.

In view of the national coal position, and in the interests of internal fuel economy, during times of low power demand from the works (weekends, etc.), it was decided to seek the permission of the Yorkshire Electricity Board, from whom a large supply of power is taken, to operate in parallel with the grid system, and also be able to feed power back into this system whenever possible.

The steam system is controlled from the power-house control room, and this has been made possible by modifying the low-pressure turbo-alternators to operate on inlet pressure governing. By this means the low-pressure system is maintained at constant pressure.

As the steam demand on the low-pressure system varies considerably, owing to variations in the uses of this steam, the low-pressure boilers can now operate at steady loads owing to the load variation being taken up on the low-pressure turbo-alternators; hence the control engineer is able to decide from variations in the electrical generation on the low-pressure machines whether to increase the rate of steaming.

The steam and power scheme and its control room are housed in the old power house.

Training

Naturally the question of training of operators for this vastly different scheme was very important. Instruction was given by staff engineers as the plant was being assembled, and the North Lindsey Technical College ran a very good course in boiler operation, which a number of operators joined. In addition, training still goes on in regular practice runs and in discussion of problems on the shop floor. The value of this training has been amply demonstrated by the way in which the operators have responded in sudden emergencies which have occurred from time to time.

Transfer of Rod Mill from South Wales

One further task remained, namely the installation of the rod mill, which was then working at the Castle Works of Guest, Keen and Nettlefolds Ltd., at Cardiff.

This was an excellent example of teamwork and co-operation; staff engineers erected the building, installed the mill drives and all electric plant, prepared all foundations and erected the billet reheating furnace and the overhead cranes, and put in all railroads.

The G.K.N. engineers demolished the mill in Cardiff on 20th December, 1951, and it was conveyed by special trains to Scunthorpe. The assembly was carried out and completed by 11th February, 1952. The mill thus began rolling 53 days after leaving Cardiff.

Acknowledgments

More detailed papers have been published by Mr. J. A. Peacock, Director and Chief Engineer, on the reconstruction of the melting shop (*J. Iron Steel Inst.*, 1954, vol. 178, Nov., pp. 301–305) and the blooming and billet mills (B.I.S.R.A. Conference on the Design of Rolling Mills, June, 1952, pp. 11–22), and by Mr. C. L. Reid, Steam Services and Power Station Engineer, on steam and power development (*Iron Coal Trades Rev.*, 1955, vol. 170, 11th March, pp. 551–557). The author wishes to acknowledge his indebtedness to these gentlemen for the use of their articles, from which he has quoted freely during the preparation of this paper.

Development of Chemical Treatment of Low-Grade Iron Ores at Appleby-Frodingham

By L. Reeve, B.Sc., Ph.D., F.I.M.

SYNOPSIS

The paper refers to the difficulties encountered in previous attempts to concentrate low-grade ores by purely physical methods, and then describes a cyclic chemical process for treating these ores, involving the use of hydrogen chloride gas or aqueous hydrochloric acid, in which the iron is distilled from the ores as pure ferric chloride at 300–350° C. This is then treated with steam to produce pure ferric oxide, or with hydrogen to produce metallic iron, in both cases regenerating hydrogen chloride gas which can then be used again. Approximate equilibria data have been determined and the influence of water vapour and ferric chloride concentration in the gases on the reaction velocities has been examined.

Vanadium present in these ores can also be distilled from them as a complex of vanadium chloride, and recovered as V_2O_5. Chlorides remaining in the tailings can be regenerated by treatment with steam mixed with air or inert gases.

Fluidizing techniques have been applied to these processes.

A brief reference to the thermodynamics of these reactions and to some of the chemical engineering problems encountered in attempting to translate them to the pilot-plant scale is also given.

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Introduction

THE HOME-PRODUCED IRON ORES used at Appleby-Frodingham are the lowest-grade iron-bearing materials employed on an industrial scale anywhere in the world. Nevertheless, despite the production of 26 cwt. of slag for every ton of iron made, coke consumptions and outputs on the furnaces using these ores have been improved to a degree which makes them comparable with practices using much richer ores. This has been achieved by extensive ore preparation, and in particular by the application of improved sintering techniques to the maximum degree possible.

While these methods were being developed, a simultaneous attack was carried out on the difficult problem of concentrating these low-grade ores. The successful outcome of the sintering developments has made concentration of British low-grade ores a less vital necessity than it was some years ago. Nevertheless, in view of the very important advances which have been achieved in these concentration experiments, it was felt desirable to report the results and to indicate how far certain new methods have been developed at Appleby-Frodingham. It is not the purpose of this paper to go beyond a description of these methods; nor will the author attempt to assess at this stage the economics of the processes described, beyond saying that he feels that under certain circumstances they could be sufficiently favourable to justify application on an industrial scale.

The possibility of concentrating the low-grade ores used at Appleby-Frodingham to raise their iron content, and reject as much as possible of their high content of slag-producing constituents, has been under consideration at Appleby-Frodingham for a good many years. The writer published in 1948 the first results of an attempt to enrich these ores by roasting, followed by magnetic concentration.[1] He concluded that whilst it was possible to enrich the limy Frodingham ores to an appreciable extent by removing a considerable proportion of the free calcite, leaving an approximately self-fluxing burden containing 36–38% Fe, very little could be done to improve the more siliceous Northamptonshire ores. This was due to the petrographic structure of these ores, which, in the case of certain Frodingham ore, consisted essentially of ooliths of limonite, together with massive calcite fossil remains in a matrix consisting largely of calcite. Magnetic concentration of these ores resulted in the rejection of a proportion of the calcite into the tailings, so raising the iron content of the magnetic fraction. In the case of many of the Northants ores, however, chamosite ooliths are embedded in a matrix of siderite and little separation of iron-rich material is possible. As chamosite is essentially a chemical compound of iron and alumino-silicates of the general formula $Al_2O_3.2SiO_2.3Fe(Mg)O.3H_2O$, it cannot be concentrated by a purely physical process.

The lack of response of the siliceous Northamptonshire ores to magnetic concentration neutralized the more favourable response of the limy Frodingham ores, since there was no point in introducing a concentration process which removed the limy fraction alone, without being able to remove the corresponding siliceous fraction of the Northants ores. Otherwise, the ridiculous position would arise of having to add free lime to the latter after removing it from the former.

Some attempts were made to apply water washing processes to these ores, but with no marked success, and in general it was decided that further attempts to concentrate the siliceous ores by physical methods would have to be abandoned. At this stage consideration was given to possible processes of enrichment by chemical means, that is, the use of some chemical reagent which would attack and remove either the iron oxide or the gangue material, followed by recovery of the iron either in the metallic form or as iron oxide free from contaminating material. It was laid down that for economic reasons such recovery should be as high as possible, preferably exceeding 90%; furthermore, the chemical reagent used must be recoverable to the extent of at least 95% in a simple

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and economical manner, so as to be used again for treatment of fresh ore. Alternatively, it must be so cheap in comparison with the end product as to be expendable. The most obvious chemicals which could be used to treat iron ores are the common mineral acids, viz. sulphuric, nitric, and hydrochloric acids, although some consideration had also been given to the very weak acids such as carbon dioxide and sulphur dioxide, and also to the caustic alkalis which will attack the low-grade ores under consideration. Some initial trials were also carried out with chlorine, which, in the presence of carbon, will attack these ores at temperatures from 500° C. upwards, to yield a range of volatile chlorides, including ferric chloride. This type of process was already in operation in certain industries, and, in fact, the whole field of so-called 'chlorine metallurgy' was expanding rapidly. Nevertheless, chlorine treatment of iron ores was abandoned because of:

(i) The simultaneous formation of undesirable volatile chlorides, including those of silicon, aluminium, sulphur, and phosphorus
(ii) The full recovery of chlorine uncontaminated by other gases was difficult
(iii) The cost of the carbon addition required for chlorine treatment was considerable.

Returning to the consideration of the common mineral acids, the use of hydrochloric acid appeared to be the most attractive, since it might be combined with distillation of volatile ferric chloride from the system uncontaminated by impurities; whilst recovery of the acid was relatively simple since ferric chloride can be hydrolysed very easily by steam to yield pure ferric oxide, with the evolution of hydrogen chloride gas. Thus, the basic reactions would be:

$$\underset{\text{(impure)}}{Fe_2O_3} + 6HCl \rightarrow 2FeCl_3 + 3H_2O \quad \ldots\ldots(1)$$

$$2FeCl_3 + 3H_2O \rightarrow \underset{\text{(pure)}}{Fe_2O_3} + 6HCl \quad \ldots\ldots(2)$$

The first reaction will be referred to as the chloridizing reaction and the second as the hydrolysing reaction.

Either aqueous hydrochloric acid or gaseous hydrogen chloride could be used for chloridizing; the advantages and disadvantages of both forms will be discussed later.

An alternative to the hydrolysing reaction (2) is to treat the ferric chloride with gases rich in hydrogen to produce first, ferrous chloride, and ultimately metallic iron, and regenerating hydrogen chloride gas:

$$2FeCl_3 + H_2 \rightarrow 2FeCl_2 + 2HCl \quad \ldots\ldots(3)$$

$$2FeCl_2 + 2H_2 \rightarrow 2Fe + 4HCl \quad \ldots\ldots(4)$$

Some work on these reactions has been carried out during the course of the investigations described in this paper, but most of the effort has been devoted to the steam hydrolysis reaction (2). This reaction may, under certain conditions, be carried out in two stages, viz.:

$$2FeCl_3 + 2H_2O \rightarrow 2FeOCl + 4HCl \quad \ldots\ldots(5)$$

$$2FeOCl + H_2O \rightarrow Fe_2O_3 + 2HCl \quad \ldots\ldots(6)$$

the intermediate compound being ferric oxychloride, FeOCl. The detailed discussion of this two-stage hydrolysis will also be considered later.

Another decisive factor which influenced the final choice of hydrochloric acid as the chemical reagent in these processes was the relative ease of recovery of the chlorides remaining in the ore tailings after distilling the ferric chloride. These chlorides may include those of lime, magnesia, and manganese, and when aqueous HCl was used, the chloride of aluminium. All these chlorides, particularly when in the presence of residual silica, can be hydrolysed very easily by steam at moderate temperatures, with the recovery of hydrogen chloride. Further details will be given later.

Table I

CHLORIDIZING OF NORTHANTS IRON ORE IN HCl GAS AT 300–350° C.

	Northants Ore	Tailings	Ferric Chloride	Fe_2O_3
1	2	3	4	5
SiO_2, %	17·9	54·8	Nil	0·2
Al_2O_3, %	8·05	23·07	Trace	
Fe_2O_3, %	56·8	Fe^{III} 3·2	Fe^{III} 34·4	98·9
FeO, %	0·45	Fe^{II} 0·2	Fe^{II} Nil	
TiO_2, %	0·34	0·79	Nil	
CaO, %	1·70	3·7	Nil	
MgO, %	0·35	1·08	Nil	
MnO, %	0·32	1·15	Trace	
P_2O_5, %	1·71	3·45	P = 0·024	<0·01
S, %	0·06	0·103	Nil	<0·01
Comb. H_2O + CO_2, %	12·30	... Cl = 5·86	... Cl = 65·12	0·18
Fe, %	40·1	3·4	34·4 $FeCl_3$ = 99·52	69·2

PRELIMINARY EXPERIMENT ON TREATMENT OF NORTHANTS ORE BY HYDROCHLORIC ACID GAS

The treatment of iron oxide in hydrogen chloride gas at 300–400° C. can be used to remove the iron almost quantitatively. This procedure was used as far back as 1899 by Gooch and Havens[2] for the separation of iron and alumina in quantitative analysis, although this analytical method has now fallen into disuse. The application to Northants ores was first attempted by the author in January, 1949, using a small rotary kiln, 4 in. in diameter. The kiln contained 500 g. of Northants ore, all below $\frac{1}{4}$ in. in diameter, and was heated externally to about 300° C. with a line of gas jets, whilst being rotated slowly by means of an external chain drive; a stream of hydrogen chloride was led through the kiln.

Ferric chloride was distilled and collected in an external condenser but the rate of reaction was slow. After 11 hr. of operation, 70% of the total Fe had been distilled from the ore. The sides of the kiln were caked with partially chloridized material.

APPLICATION OF FLUIDIZING TECHNIQUES

About this time considerable interest was being shown in chemical engineering circles by developments in the technique of fluidized reactors. This procedure involves partial or full suspension of a solid powdered reactant or catalyst in a reacting gas stream, with attendant advantages of uniformity of temperature control, intimacy of contact between gas and solid, and rapid reaction. These advantages had already been shown in Germany in the Winkler gas

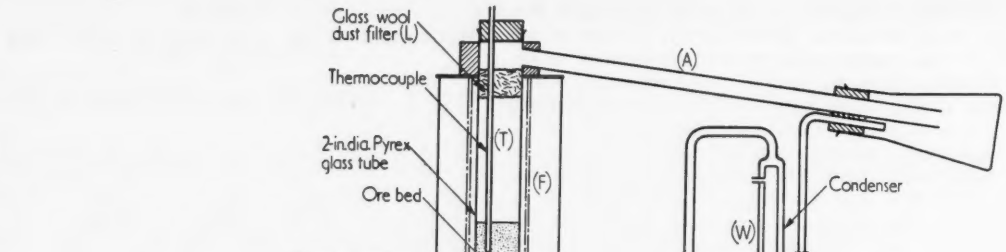


Fig. 1—Apparatus for the distillation of ferric chloride from beds of ore fluidized in HCl gas

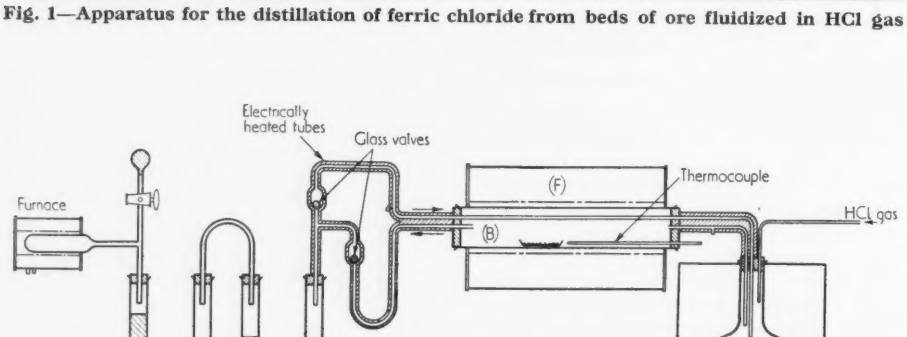


Fig. 2—Circulation apparatus for HCl/H_2O equilibria determinations over Fe_2O_3

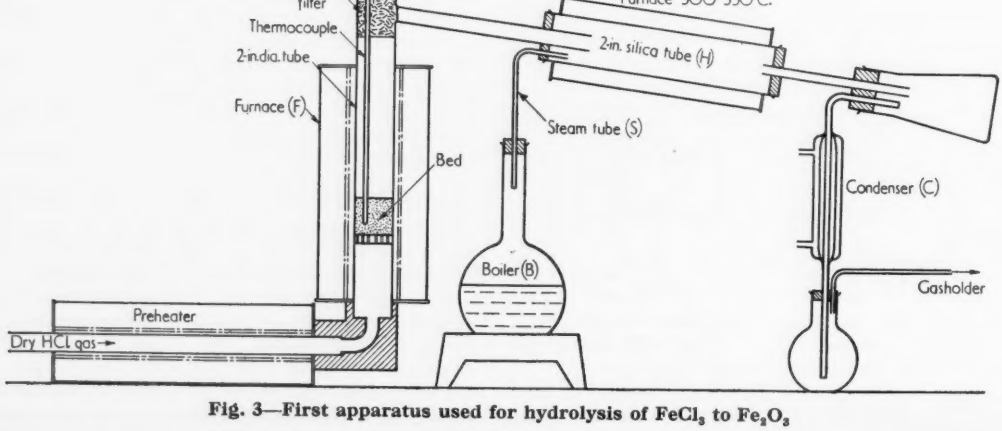


Fig. 3—First apparatus used for hydrolysis of $FeCl_3$ to Fe_2O_3

producer, and in the U.S.A. in fluidized catalytic oil-cracking equipment, very large units of which had been installed. The author became aware of these processes just about the time when these first chloridizing experiments in the small laboratory kiln were being carried out, and thought it probable that a considerable speeding up of the reaction would result if it were fluidized, if only because of the smaller particle size used. He therefore repeated the trials on the same Northants ore as used in the kiln experiment in the small fluidized unit shown in Fig. 1, at a temperature of 300–350° C. The ore was crushed to 30–60 mesh and supported on a perforated graphite disc, *D*, in the tube furnace *F*, shown. The analysis of the ore used is given in Table I, column 2.

After a preliminary heating up in a stream of air, hydrochloric acid gas was pumped through the tube at a rate of approximately 2200 l./hr. (corresponding to a linear rate of about 30 cm./sec.), which preliminary experiments had shown to be sufficient to put the ore into a marked condition of turbulence equivalent to boiling, but which was low enough to prevent blowing out of the bed all but the finest particles. A filter of glass wool, *L*, prevented these leaving the reactor.

The hydrochloric acid gas was stored in an oil-sealed gasholder from whence it was drawn by a small rotary pump. After passing through an electrically heated gas preheater, *P*, it entered the 2-in. dia. reaction tube *T*. The reaction products entered the air condenser tube, *A*, followed by a water-cooled condenser, *W*, and thence back to the gasholder, after passing through the glass wool packed tower, *G*, which acted as a mist filter.

Almost as soon as the HCl gas was allowed to enter the reaction tube a stream of yellowish ferric chloride vapour was evolved, which soon condensed on the walls of the air condenser as typical dark brown anhydrous crystals. An aqueous mist formed beyond this and condensed in the water-cooled condenser, *W*, and the receiver *B*, carrying with it a small amount of uncondensed ferric chloride. Most of the reaction was complete within 60 min., but it was allowed to proceed for a further 30 min. and the equipment was then closed down. Examination of the residue showed it to consist of buff-coloured ' tailings ' of approximately the same size as the original ore, the analysis of which is given in Table I, column 3.

Calculation from the analysis and weight of original ore and final tailings indicated that 96% of the original Fe had been distilled. The ferric chloride crystals removed from *A* analysed 34·4% Fe, which compares with 34·5% for pure $FeCl_3$. The slight impurities reported in the ferric chloride are due to dust carry over. Particular attention should be drawn to the fact that all the sulphur and all but a trace of the phosphorus in the original ore remained in the tailings.

On hydrolysis of a similar ferric chloride with steam, as described later, a substantially pure ferric oxide, analysing as shown in column 5 of Table I, was obtained.

It was evident from this basic experiment, which was first carried out in February, 1949, that the application of fluidizing technique to the chloridizing of low-grade ores by means of hydrochloric acid gas had resulted in a marked improvement in the speed of the reaction and in convenience of operation, and the procedure might well form the basis of a possible industrial process.

Table II

CHLORIDIZING OF OXFORD AND NORTHANTS ORES

	A	*B*	*C*	*D*	*E*
Fe, %	41·7	28·9	43·7	40·7	38·7
FeO, %	0·13	4·09	0·64	2·56	0·38
Fe_2O_3, %	59·50	36·75	61·80	55·20	54·10
SiO_2, %	14·80	9·60	10·30	9·80	7·50
Al_2O_3, %	8·32	6·23	7·69	6·39	6·44
TiO_2, %	0·25	0·19	0·25	0·18	0·19
CaO, %	8·00	19·80	9·00	11·20	15·60
MnO, %	0·15	0·19	0·15	0·33	0·22
MgO, %	0·79	2·74	1·37	1·22	0·58
S, %	0·069	0·38	0·38	0·906	0·109
P_2O_5, %	2·156	1·860	2·34	1·75	1·97
$H_2O + CO_2$, %	5·61	18·48	5·97	9·18	11·44
Tailings					
Fe, %	5·40	7·10	7·00	4·80	7·10
FeO, %	0·65	1·40	1·28	1·79	1·20
Fe_2O_3, %	7·01	8·58	8·58	4·86	8·86
SiO_2, %	29·80	16·32	22·60	21·50	14·90
Al_2O_3, %	17·34	10·59	15·61	12·82	12·86
TiO_2, %	0·56	0·34	0·56	0·36	0·36
CaO, %	17·30	28·20	18·60	24·20	30·20
MnO, %	0·32	0·33	0·32	0·59	0·45
MgO, %	1·55	4·12	2·93	2·33	1·14
S, %	0·14	0·64	0·77	1·74*	0·23
P_2O_5, %	4·27	3·16	4·95	3·57	3·81
Cl, %	8·73	14·60	9·80	13·30	9·60
$CO_2 + H_2O$, %	11·90	13·20	14·90	14·60	19·20
Percentage of initial Fe stripped	94	86	93	94	91

* Note high sulphur in tailings

EXPERIMENTS ON OTHER LOW-GRADE ORES

Other Northamptonshire and Oxfordshire Ores

Similar chloridizing tests have since been carried out on the Northants and Oxfordshire ores listed in Table II, crushed to −16 mesh, with substantially similar results, as shown in the Table.

Ores rich in FeO will lose the equivalent amount of iron as ferrous chloride in the tailings, since ferrous chloride is non-volatile at the chloridizing temperatures of 300–350° C. used in these experiments, and it is advisable to oxidize such ores beforehand in a stream of air at about 400–600° C. to increase iron recovery.

French Ore

Similar tests have been carried out on the French ore listed in Table III, again with similar results.

Limy Ores, including Frodingham Ores

Some of the ores listed in Tables II and III are appreciably more limy than the original Northants ore listed in Table I. The only effect on the results is to increase the content of calcium chloride in the

Table III
CHLORIDIZING OF DIFFERENT TYPES OF LOW-GRADE ORE

	French Ore		Frodingham Ore	High-Sulphur Ore (Frodingham)	American Taconite
SiO_2, %	24·15		7·50	7·70	42·75
Al_2O_3, %	4·05		4·28	4·45	0·84
Fe_2O_3, %	36·47		22·29	21·59	37·43
FeO, %	10·88		8·10	8·96	11·77
TiO_2, %	0·13		0·16	0·18	Trace
CaO, %	5·50		24·39	23·80	2·20
MgO, %	1·67		1·63	1·78	0·32
MnO, %	0·47		1·58	1·75	1·12
P_2O_5, %	1·43		0·98	0·89	0·082
S, %	0·024		0·412	2·91	0·041
Comb. $H_2O + CO_2$, %	13·60		27·8	26·10	3·79
Fe, %	34·0		21·9	22·10	35·4
V, %	0·049		0·048	0·044	Trace
Fe stripped at 300–350° C. in 2–3 hr., %	Raw 78·8	Roasted 91·8	Raw 81·0	Raw 77·0	Roasted 98·3
V distilled, %	95·9	92·7	76·5	75·5	...

tailings, though it should be pointed out that only a proportion of the lime in the original ore is attacked by gaseous hydrogen chloride under the conditions described. Thus, in the case of a limy Frodingham ore analysing as shown in Table III, after treatment with HCl gas at 300–350° C., the tailings contained 29% calcium but only 11·9% chlorine, which is the equivalent to only 6·7% calcium as $CaCl_2$. Hence, only about 23% of the original calcium had been converted to $CaCl_2$. The main objection to a higher content of $CaCl_2$ in the tailings will be the somewhat longer time, and increased thermal requirements, of hydrolysis of the tailings to recover this chlorine (*see* p. 34).

High-sulphur Ores

The high-sulphur Frodingham ore listed in Table III gave a somewhat low iron recovery (77%). This was due to the fact that it was tested in the unroasted condition and contained appreciable ferrous iron. All the sulphur was retained in the tailings.

American Taconites

The process has been applied to an American taconite whose analysis is also listed in Table III. This was crushed to −30 mesh and fluidized in HCl gas at 300–400° C. Rapid chloridizing took place with the recovery of 98·3% of the original Fe after 180 min. treatment.

The particle size of the Fe_2O_3 in the original taconite ore was extremely small and it would be necessary to crush the rock to 300 mesh to concentrate it by more normal processes such as magnetic concentration.

The references to vanadium distillation in Table III will be discussed in greater detail on p. 37.

EXPERIMENTS WITH AQUEOUS HYDROCHLORIC ACID

Before the experiments reported above had been carried out using gaseous hydrogen chloride, some trials on Northants ore, using aqueous hydrochloric acid, had been attempted.

The first experiment of this type was carried out in 1946, when a strong hydrochloric acid extract of Cottesmore ore, after filtering off the insoluble siliceous residue, was allowed to drip down a heated 1-in. tube packed with glass beads countercurrent to a stream of HCl gas at a temperature of 320° C.; 86·2% of the Fe content was distilled as $FeCl_3$. The beads became locked in the tube owing to encrustation with a residue of ' tailings ' containing, amongst other materials, dried-out $CaCl_2$, $MgCl_2$, and Al_2O_3.

Further investigation of this process was not pursued at the time, owing to pressure of other work, and subsequently because of the considerable programme of tests arising from the application of gaseous hydrogen chloride to the treatment of the various ores mentioned above. More recently, further tests involving the use of aqueous hydrochloric acid have been carried out in which the acid extracts have been evaporated in contact with fluidized sand (or siliceous tailings from previous ore treatments), again in a stream of hydrogen chloride gas at temperatures ranging from 200° to 350° C.; or alternatively by allowing a fine spray of the extract to fall through a stream of hot hydrogen chloride gas.

There are a number of potential advantages in employing aqueous acid extracts of ore, as opposed to treatment of the dry ore in gaseous hydrogen chloride, which will be appreciated more clearly after a fuller account has been given of the work on gaseous processes. There are inherent economic advantages in an aqueous process, in that the ore can be treated with hydrochloric acid substantially in the as-mined condition, without drying, roasting, or crushing to fine sizes, as is necessary for the dry process. Moreover, whilst, as indicated, gaseous HCl has to be employed in drying out the strong aqueous solutions and in evaporating the ferric chloride, there is reason to believe that the volume required is less than in the dry processes.

Finally, even the dry processes inevitably produce appreciable quantities of aqueous acid condensates, which contain some ferric chloride carried over from other sections of the plant, and methods have had to be developed to deal with these solutions.

Table IV

APPROXIMATE H_2O/HCl/IRON ORE EQUILIBRIA DATA
4-hr. Circulation in Each Case

1	2	3	4	5	6	7	8	9	10
Test No.	H_2O in HCl, vol.-%	Temp., °C.	Weight Change, g.	Original Fe, %	Residue				Fe Sublimed, % of Original Fe
					Fe, %	Total Cl, %	Insol. Cl, %	Sol. Cl, %	
1	10	200	+1·06	42·2	22·8	39·55	1·06	38·49	17·3
2	20	200	+1·04	42·2	23·9	42·95	1·77	41·18	13·9
3	30	200	+0·45	42·2	23·4	40·6	1·20	39·4	32·1
4	10	250	+0·160	42·2	32·8	19·45	16·05	3·40	16·1
5	30	250	+0·27	44·0	35·8	20·16	15·40	4·76	7·7
6	10	300	+0·088	42·2	34·2	16·47	Mainly insol.		15·4
7	10	300	+0·001	42·2	33·0	16·75	,,		21·8
8	10	300	+0·031	42·2	35·2	12·14	,,		15·4
9	20	300	+0·089	42·2	34·9	14·34	,,		13·6
10	20	300	+0·079	42·2	35·6	11·5	,,		13·0
11	20	300	+0·067	42·2	34·4	14·9	,,		15·8
12	20–25	300	+0·046	42·2	36·4	10·9	,,		11·7
13	30	300	−0·062	44·0	42·8	3·76	1·63	2·13	5·7
14	10	550	−0·120	42·2	41·2	1·34	...	...	5·8
15	15	550	−0·076	42·2	43·0	0·76	...	...	1·6
16	20	550	−0·099	42·2	44·4	0·37	...	...	Nil

A fuller account of these aqueous processes will be given in a later paper. For the moment the author will proceed with a fuller description of the development of the dry process and in particular with further details of the hydrolysis of the chlorides produced to recover their HCl content.

HYDROLYSIS OF FERRIC CHLORIDE

To obtain information on the percentage of H_2O in HCl gas required to hydrolyse ferric chloride, i.e. to reverse the chloridizing reaction (1), a series of approximate equilibrium determinations were carried out in the temperature range 250–550° C. in which known mixtures of HCl and H_2O were circulated over iron ore, or pure iron oxide, in a porcelain boat, *B*, in the tube furnace *F*, shown in Fig. 2. The circulating pump used was of the oscillating mercury column type, the mercury being kept from contact with the HCl gas by an intermediate oscillating column of heavy oil, *O*.

The H_2O content of the circulating gas was kept at any desired figure between 5% and 30% by volume, by passage through the flask, *S*, containing sulphuric-acid–water mixtures of suitable concentrations, maintained at 100° C. by means of the external water bath, *W*. From the known vapour pressures of these sulphuric acid solutions at 100° C., the H_2O vapour content of the circulating gas was modified as desired; HCl gas is practically insoluble at a temperature of 100° C. in the range of H_2SO_4 solutions used, and its presence did not seriously affect the results.

Check determinations, in which the H_2O in the gas was determined directly by condensation, confirmed the accuracy of the method. In order to prevent condensation of water in the connecting glass tubes of the apparatus, they were heated by Nichrome spirals wound directly on to the surface, through which controlled electric heating currents were passed. Some representative results after 4-hr. circulation are given in Table IV. From these results it may be concluded that at 550° C. 20% of H_2O by volume in the gas will suppress chloridizing almost completely, whereas appreciable chloridizing will take place at 300° C., and very marked chloridizing at 200° C. in the presence of the same amount of water vapour. The insoluble chloride mentioned in column 8 of the Table is ferric oxychloride, FeOCl, the formation of which is discussed further on p. 33.

In general, hydrolysis is favoured by raising the temperature and chloridizing by lowering it, as would be expected from the exothermic nature of the chloridizing reaction (1). A fuller discussion of the thermodynamics of the process will be found in a later section. Meantime, it appeared from these approximate equilibria determinations that an 80/20 HCl–H_2O mixture by volume should be capable of hydrolysing $FeCl_3$ almost completely at about 500–550° C. This conclusion was checked in a trial in the apparatus shown in Fig. 3, in which a stream of HCl carrying $FeCl_3$ vapour from the fluidized Northants ore bed in the vertical tube furnace, *F*, was carried into the horizontal silica tube furnace, *H*, heated to 500–550° C., where it was treated with steam introduced from the boiler, *B*, through tube *S*. The steam flow was adjusted to approximately 20% of the exit gas volume, this being subsequently checked by the volume of the condensate in the condenser, *C*.

Table V

THE CONVERSION OF FERRIC CHLORIDE VAPOUR TO FeOCl

Bed Temp., ° C.	Period, min.	Inlet Gas		Exit Gas		Percentage of Initial Fe_2Cl_6 in Gas Deposited on Bed
		Fe_2Cl_6, wt.-%	H_2O, wt.-%	Fe_2Cl_6, wt.-%	H_2O, wt.-%	
310	60	10·5	5·8	0·8	5·5	92·4
310	90	8·5	6·5	1·3	6·2	86·2
310	90	12·6	6·6	0·9	6·3	93·9

Hydrolysis of the $FeCl_3$ to Fe_2O_3 took place on the walls of the silica tube, *H*, the percentage of $FeCl_3$ converted being 81% in a tube about 2 ft. long. The Fe_2O_3 could be removed from the tube wall as a sheath of loosely adherent material and was found to analyse:

Fe_2O_3	98·9% (Fe 69·2%)
Cl	0·18%
SiO_2	0·2%
S and P	<0·01%

Similar equipment was used in subsequent trials in which a stainless-steel tube was used for the hydrolyser, this being filled with internal baffles to increase the surface area and improve the recovery of Fe_2O_3.

Sundry experiments showed that Fe_2O_3 could be produced in this way on the surface of various materials, including silica, alumina, and most important of all, on pieces of iron ore, including Kiruna and Cumberland hematite. It was then realized that the best method of hydrolysing the $FeCl_3$ vapour to Fe_2O_3 would be on the surface of fluidized particles of rich iron ore such as the ores mentioned. This has now become the standard method for the hydrolysis of the distilled $FeCl_3$, the type of laboratory equipment used being shown in Fig. 4, and on the small pilot-plant scale in Fig. 5.

The equipment consists of a fluidized chloridizer, *C*, followed by a fluidized hydrolyser, *F*, and finally by a condenser system, *E*, to remove the excess water vapour, allowing the remaining gaseous HCl to be returned to the gasholder for further use. Steam for hydrolysis is supplied by a small boiler, *B* (in Fig. 4), or from the steam main in Fig. 5.

INFLUENCE OF TEMPERATURE AND MOISTURE CONTENT ON MECHANISM OF HYDROLYSIS OF $FeCl_3$

Subsequent investigation has shown that under certain conditions of moisture content and temperature, the hydrolysis of $FeCl_3$ can produce ferric oxychloride, FeOCl, in accordance with equation (5), rather than Fe_2O_3 in accordance with equation (2). Broadly, at temperatures in the range 250–400° C., and with moisture contents of approximately 10–12% by volume, or 6% by weight, FeOCl production is encouraged in preference to Fe_2O_3. This is confirmed by the results already reported in column 8 of Table IV, but these results were obtained under static (non-fluidized) conditions.

Some typical results at 300–310° C. under fluidized conditions are shown in Table V. Some carry over of unchanged $FeCl_3$ occurs as shown. All these hydrolyses were carried out on the surface of fluidized Kiruna ore, the $FeCl_3$ vapour being produced either by passing HCl gas through fluidized Northants ore at 350° C. or through a fluidized mixture of sand and anhydrous ferric chloride at a suitably controlled temperature to give the desired vapour pressure.

Ferric oxychloride is a reddish-brown and rather soft solid which is insoluble in water, thus distinguishing it clearly from ferric chloride and the other soluble chlorides produced in these experiments. It can be hydrolysed to Fe_2O_3 by further treatment with additional steam, steam–air, or steam–HCl mixtures at about 500° C., as shown in Table VI. It will be noted that conversion at 400° C. is incomplete.

Economic assessments which have been made have indicated that there would be definite economic advantages in large-scale production if $FeCl_3$ were hydrolysed in two stages—firstly to FeOCl and then to Fe_2O_3. The reasons for this are best explained by an example which will incidentally give some idea of the chemical engineering factors which have to be considered when assessing the economics of these processes.

Under certain operating conditions it was found necessary to use 450,000 cu. ft. of HCl gas to distil, from a bed of fluidized ore at 300° C. the volume of

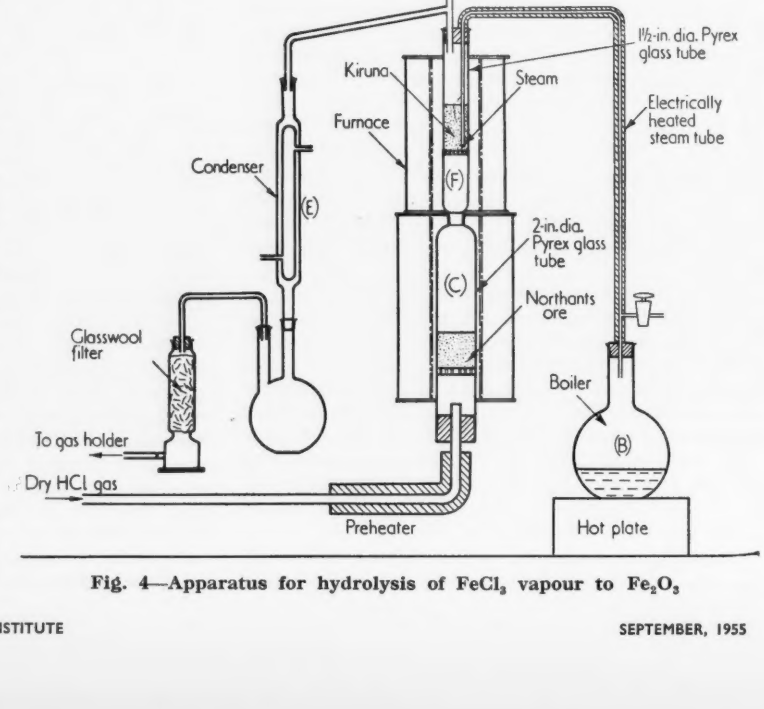


Fig. 4—Apparatus for hydrolysis of $FeCl_3$ vapour to Fe_2O_3

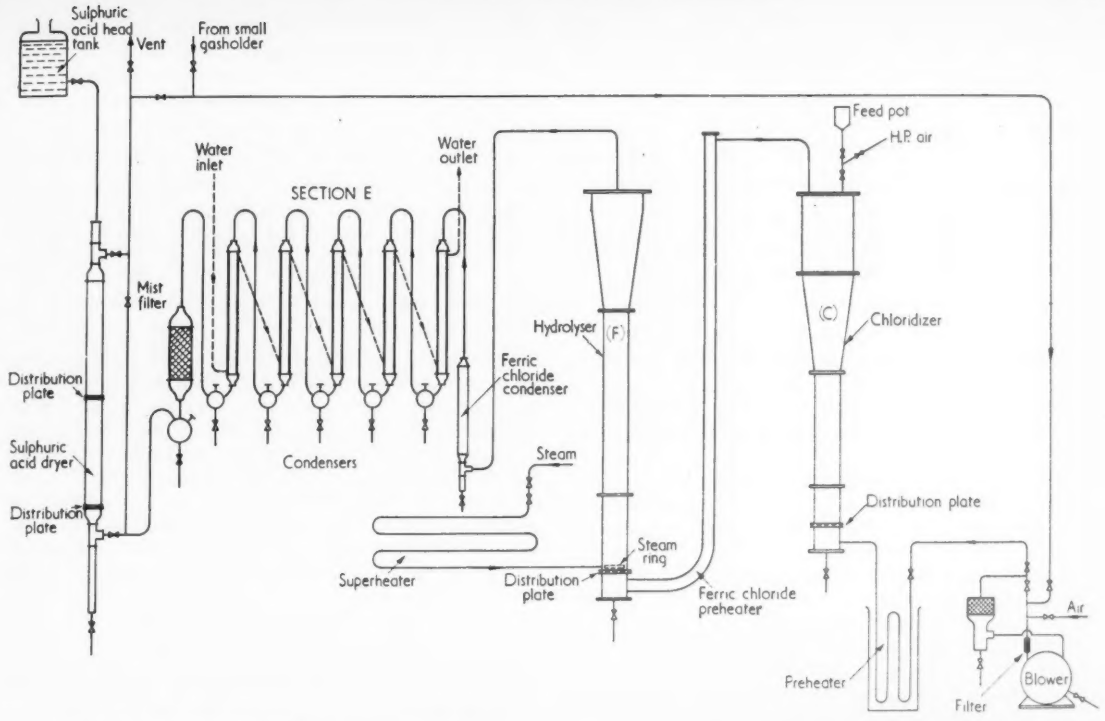
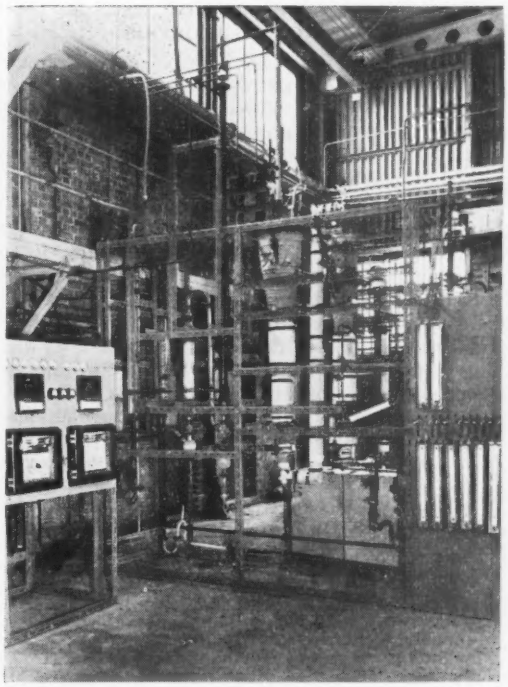


Fig. 5—Chloridizer and hydrolyser—small pilot-plant unit

$FeCl_3$ corresponding to 1 ton of Fe_2O_3. The greater part of this, viz. about 420,000 cu. ft., is excess HCl gas, which leaves the chloridizing chamber at 300° C. carrying the ferric chloride vapour with it. To hydrolyse this ferric chloride to ferric oxide in one stage at 500° C. requires a volume of steam in the exhaust gases amounting to approximately 20% of the total gas volume, or about 110,000 cu. ft. per ton of Fe_2O_3. The total effluent gas volume of about 550,000 cu. ft. has to be raised from 300° to 500° C. before hydrolysis, involving an expenditure of heat of over 4 million B.Th.U., whilst the excess steam has ultimately to be condensed, requiring a large and expensive condensing surface.

If, however, the same gas volume of HCl gas and ferric chloride vapour were first passed through an FeOCl type of hydrolyser at 300° C., it would require the addition of only 10% of steam by volume of the exit gases, or, say, 50,000 cu. ft. of steam, and since the gases are already at the operating temperature of 300° C., they require no further addition of heat to raise it to the operating temperature. Thus there is an immediate saving of 4 million B.t.u. per ton of Fe_2O_3. Finally, the steam would have to be condensed as before, but as its volume is only about half of that leaving the single-stage hydrolyser, the surface area of condenser required would also be reduced. As these condensers have to be built of either glass or carbon tubing (to resist the aqueous HCl formed), they are relatively expensive units, and reducing their load would result in appreciably lower capital costs for the equipment.



It may be objected that the FeOCl produced still requires final hydrolysis to Fe_2O_3, and that this must be carried out at a higher temperature of the order of 550° C., but this can be done in a separate vessel,

Table VI

HYDROLYSIS OF FeOCl TO Fe_2O_3 IN FLUIDIZED BEDS

Temp., °C.	Period, min.	Composition of Initial Bed, %				Gas, wt.-%			Composition of Final Bed, %				
		Fe	Total Cl	Sol. Cl	FeOCl	H_2O	HCl	Air	Fe	Total Cl	Sol. Cl	Insol. Cl	FeOCl
400	30	56·6	15·8	2·8	39·0	52·8	47·2	...	62·4	7·0	3·0	4·0	12·0
500	60	56·6	15·8	2·8	39·0	20·0	...	80·0	66·0	0·3	0·3	Nil	Nil
500	30	56·6	15·8	2·8	39·0	23·5	76·5	...	65·2	1·0	1·0	Nil	Nil
500	30	60·0	11·7	1·8	29·7	23·5	...	76·5	67·4	0·5	0·4	0·1	0·3

into which the powdered FeOCl from the first-stage hydrolyser is transferred. The volume of steam required for this purpose is quite low, being limited by the stoichiometric requirements of equation (4), viz.:

$$2FeOCl + H_2O \rightarrow Fe_2O_3 + 2HCl$$

Even allowing for, say, a 30% content of steam in the exit gases, the steam requirement amounts to only 10,000 cu. ft. per ton of Fe_2O_3, whilst the additional heat requirements amount to only about 100,000 B.t.u. per ton of Fe_2O_3. Whilst these figures require slight adjustment to cover solids heating, it is clear that there is a very marked overall saving in heat requirements and in the size of the condensing and evaporating equipment required to handle the exit steam, by using the two-stage hydrolysis process for converting $FeCl_3$ to Fe_2O_3.

TAILINGS HYDROLYSIS

Table I shows that the tailings remaining after distilling the iron out of Northants ore contained a residual Cl of 5·86%. Further examination showed that this was present in the tailings mainly as $CaCl_2$, with smaller amounts of $MgCl_2$, $MnCl_2$, $FeCl_3$, and some ferrous chloride, $FeCl_2$, depending upon the amount of ferrous iron in the original ore.

In the case of more limy ores, such as the Frodingham ore described on p. 29, the Cl remaining in the tailings will increase still further, though not necessarily in direct proportion to the CaO in the original ore. Percentages of residual chlorine as high as 14·6% have been reported in the tailings of such ores when using gaseous HCl as the chloridizing medium. In aqueous processes, practically all the CaO, MgO, and Al_2O_3 in the ore will be converted into the equivalent chlorides. In all cases, and particularly with the more limy ores, it is essential for the economy of the process to recover this combined Cl as HCl, and thus avoid the relatively high cost of make-up HCl to maintain the cyclic process. Fortunately, it has been found possible to do this by heating the tailings in combustion gases containing steam at about 600° C., as a result of which the chlorides are hydrolysed to produce the oxide and releasing HCl gas. This process is considerably accelerated by the presence of siliceous matter in the tailings, which combines with the bases to form silicates:

$$CaCl_2 + H_2O \rightarrow CaO + 2HCl$$
$$xCaO + ySiO_2 \rightarrow xCaO.ySiO_2$$

Alumina in the tailings also helps, presumably by forming aluminates.

Some indications of the extent and speed of these reactions are shown in Table VII.

The HCl present in the exit gases from these hydrolysing reactions can be utilized either by passage through incoming ore, or by condensation as aqueous HCl. Even NaCl can be hydrolysed on the tailings in this manner, provided that the quantity is limited to about 10%. As NaCl is very much cheaper than HCl (per ton of Cl), it could be used to make up the inevitable small losses of HCl gas in these processes, if carried out on an industrial scale. This could be done by adding small percentages of salt to the tailings during hydrolysis, or if more convenient, to the incoming ore. It will be noted that all these chloride hydrolyses reactions are again carried out most conveniently under fluidizing conditions.

INFLUENCE OF TEMPERATURE AND MOISTURE CONTENT OF GAS ON CHLORIDIZING OF IRON ORE

It is apparent from Table IV that chloridizing of

Table VII

HYDROLYSIS OF VARIOUS CHLORIDES ON SILICEOUS CARRIERS IN STEAM–AIR MIXTURES

Chloride Used	Carrier	Chloride, %	Temp., °C.	Period, hr.	Initial Cl, g.	Final Cl, g.	Degree of Hydrolysis
Magnesium chloride	Northants ore	11·0	500	1·0	2·31	0·17	93·0
Manganous chloride	Northants ore	11·0	500	1·0	1·72	Nil	100·0
Calcium chloride	Silica flour	33·3	500	2·5	5·30	1·61	69·6
Calcium chloride	Northants tailings	20·0	550	2·0	2·86	0·09	96·8
Sodium chloride	Northants tailings	11·0	600	3·5	4·52	0·49	89·0
Sodium chloride	Kaolin	11·0	600	3·0	1·80	0·499	72·0
Calcium chloride	Silica from Northants ore	26·0	700	1·5	13·68	1·85	86·5

iron ore is favoured by lower temperatures, as would be expected from the exothermic nature of the basic chloridizing equation (1):

$$Fe_2O_3(s) + 6HCl(g) = 2FeCl_3(s) + 3H_2O(l) + 62{\cdot}6 \text{ kcal.}$$

(s) = solid system; (g) = gaseous system; (l) = liquid system.

The heats of formation used in calculating this heat of reaction are for solid $FeCl_3$ and liquid water. As the temperature of reaction is raised, the vapour pressure of $FeCl_3$ (or strictly speaking, Fe_2Cl_6) rises from 15 mm. at 250° C. to 760 mm. at 324° C., and in view of its high latent heat of vaporization the reaction becomes considerably less exothermic. Whilst exact information is lacking, the heats of reaction at 250° and 350° C. are as follows:

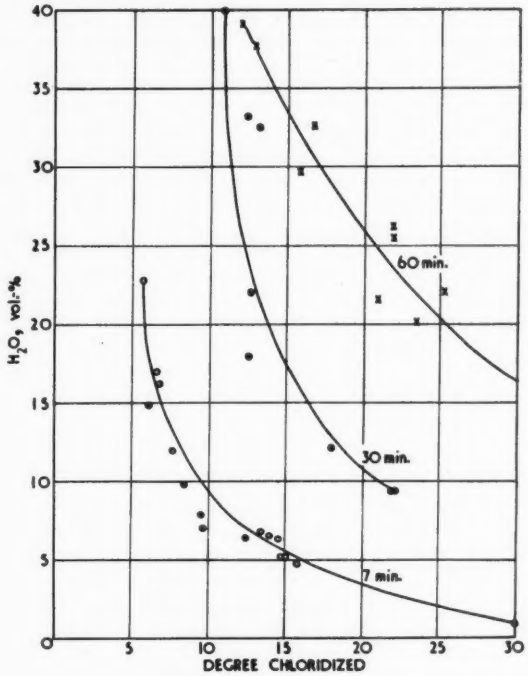
At 250° C.

$$Fe_2O_3(s) + 6HCl(g) = Fe_2Cl_6(s) + 3H_2O(g) + 32{\cdot}5 \text{ kcal.}$$

At 350° C.

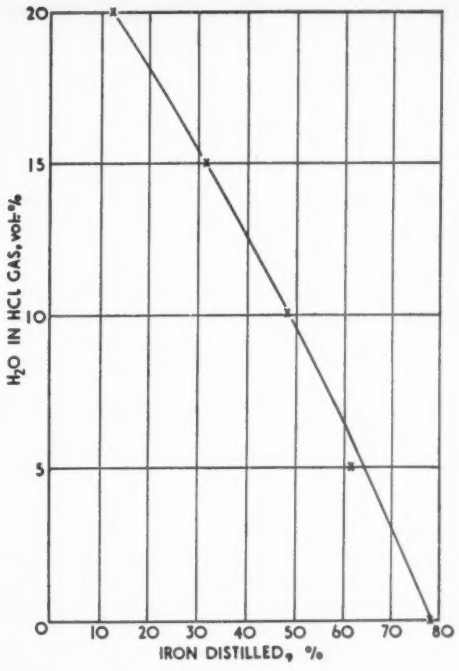
$$Fe_2O_3(s) + 6HCl(g) = Fe_2Cl_6(g) + 3H_2O(g) + 2{\cdot}8 \text{ kcal.}$$

From the thermodynamics of the process, one would therefore expect the equilibria of the reaction to be well over to the right at low temperatures, and that possibly chloridizing rates would be faster at low temperatures than at high. Approximate equilibria data have already been reported in Table IV, and have been confirmed in numerous experiments since carried out on the chloridizing of iron ore at temperatures from 100° C. upwards. Reaction rates between 100° and 200° C. have been found to be very fast, but unfortunately certain operating difficulties have prevented their successful use on a pilot-plant scale.



Periods of 7, 30, and 60 min.

Fig. 6—Effect of water vapour on the rate of chloridizing Northants ore at 250° C.



Distillation period 1 hr.

Fig. 7—Effect of H_2O content of gas on rate of distillation of ferric chloride in HCl gas at 350° C.

The data in Table IV also indicate that the extent of chloridizing at any given temperature is reduced with increase of concentration of water vapour in the gas. Compare, for example, the results at 300° C. in the presence of 10%, 20%, and 30% of water vapour respectively. It will be noted that the percentage of chloride in the residue and the percentage of iron distilled (as ferric chloride) are both reduced considerably as the water content of the gas is increased.

The results in Table IV were not obtained in a fluidized bed. In view of the importance of this effect of water vapour, particularly in the $FeCl_3$ distillation range, the results have been re-checked at 250° and 350° C. in a fluidized reactor, with the conclusions shown in Figs. 6 and 7. The results at 350° C. were obtained by prechloridizing a batch of Northants ore at about 250° C. to the extent of about 30%, followed by a series of runs each of 1 hr. on separate samples of this ore fluidized in HCl gas, plus controlled quantities of water vapour, the results being checked by analysis of the residues.

There is a very marked effect of water vapour on the rate of stripping of $FeCl_3$ at 350° C., 15 vol.-% of water vapour being sufficient to reduce the amount stripped in 1 hr. by 50%. Similarly, the rate of chloridizing of ore at 250° C. is also dependent on the water-vapour content of the gas. Some such effect would, of course, be expected from the mechanism of the reversible chloridizing reaction (1), since water vapour is one of the products of the reaction.

Attention was then turned to the influence of the concentration of ferric chloride vapour in the gas on

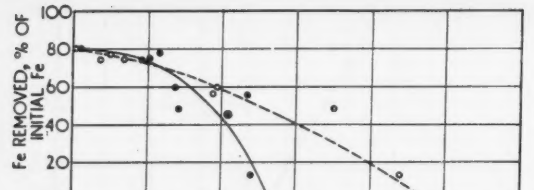


Fig. 8—Effect of Fe_2Cl_6 and H_2O vapour on the removal of iron in HCl gas

the rate of stripping of iron ore in HCl gas at about 350° C., first in dry gas and then in conjunction with increasing quantities of H_2O vapour under fluidizing conditions. The initial concentration of $FeCl_3$ vapour in the incoming HCl gas was controlled by passing it through a fluidized bed consisting of a mixture of sand and anhydrous ferric chloride at controlled temperatures between 260° and 290° C., the concentration being checked by periodic ' snap ' samples from both incoming and exit gas.

As would be expected, the most marked retarding effect was exhibited in the presence of both the products of reaction, i.e. Fe_2Cl_6 in conjunction with water vapour. Under such conditions it was found that as little as 1 wt.-% of water vapour (approx. 2 vol.-%), in the presence of 5–10 wt.-% Fe_2Cl_6, is sufficient to retard appreciably the rate of distillation. Some comparative results are shown in Table VIII.

Whilst results were not entirely reproducible, in general the rates of stripping appear to be some inverse function of the product of the ferric chloride and water vapour concentrations. A plot of the results to date is shown in Fig. 8, which suggests a linear relationship between the rate of stripping and $(Fe_2Cl_6) \times (H_2O)^3$, the concentrations being expressed as percentages by weight in the exit gas stream.

Practically, this function appears to be limited to values of about 10 to 20 if reasonable rates of distillation are to be obtained.

This marked effect of water vapour in conjunction with $FeCl_3$ has important implications on the economics of the chloridizing process, since it fixes the volume of gas required to chloridize the ore and distil the ferric chloride from it.

Before considering this in greater detail, attention should be drawn to the fact that with increasing percentage of water vapour in the gas, residual water in the chloridized ore increases, particularly at the lower temperatures, probably owing to the formation of hydrates of ferric chloride (*see* Table IX). This, unfortunately, results in stickiness of the chloridized ore, which adheres to the walls of the vessel and ultimately clogs the distribution plates when fluidizing technique is employed.

These effects may be minimized to some extent by diluting the ore with inert matter such as sand or residual tailings from previous runs, but, as would be expected, such dilution slows up the mass reaction rates proportionately to the degree of dilution. In actual fact, direct chloridizing of iron ore at 200–250° C., by means of gaseous HCl, has had to be abandoned for the time being owing to this effect, despite its attractive kinetics. Gaseous chloridizing at 300–350° C. is free from these difficulties, but unfortunately requires the use of considerably larger volumes of gas for completion than would be necessary at lower temperatures.

GAS VOLUME REQUIREMENTS FOR CHLORIDIZING (GASEOUS PROCESS)

The gas volumes required for chloridizing will be appreciated from a consideration of the stoichiometric implications of the chloridizing equation (1):

$$Fe_2O_3 + 6HCl \rightarrow 2FeCl_3 + 3H_2O$$

If this reaction went completely from left to right, i.e. if it were irreversible, 160 lb. of Fe_2O_3 could be treated with approximately $6 \times 355 = 2130$ cu. ft. of HCl, or approximately 30,000 cu. ft. per ton of Fe_2O_3. This will be referred to as the theoretical quantity and has never been attained in practice except at temperatures in the neighbourhood of 100° C., where the extent of reaction is limited by hydrate formation. At 200–250° C., gas volumes between 2 and 3 times theoretical are possible, i.e. 60,000 to 90,000 cu. ft. of HCl per ton of Fe_2O_3, but here again the reaction cannot be carried to completion for the same reason. At 300–350° C., no complications due to sticky hydrates arise, but the gas volume goes up to about 15 times theoretical, i.e. 450,000 cu. ft. of HCl per ton of Fe_2O_3. This is in line with the need to dilute the water of reaction in equation (1) until it falls to below the 1·5 wt.-% mentioned previously, as the limit desirable in chloridizing at these temperatures. Thus, the true equation at 300–350° C. is:

$$Fe_2O_3 + (15 \times 6)HCl \rightarrow 2FeCl_3 + 84HCl + 3H_2O$$

The weight percentage of water in the exit gases for this equation is about 1·6%. The corresponding percentage of water in the exit gas at 250° C. with 3 times theoretical gas is as high as 6·7%, but as already indicated, this cannot be attained in practice owing to operating difficulties.

Table VIII

STRIPPING OF $FeCl_3$ AT 300–350° C. FROM PRE-CHLORIDIZED ORE IN HCl GAS
Effect of $FeCl_3$, together with Water Vapour

H_2O in HCl Gas Stream, wt.-%	$FeCl_3$ in HCl Gas Stream, wt.-%	Time, min.	Fe Stripped from Chloridized Ore Bed, %
0·8	6·5	120	80
0·5	11·6	120	80
1·2	5·6	120	60
1·0	10·3	120	47
1·8	6·8	120	20

GAS VOLUME REQUIREMENTS FOR AQUEOUS CHLORIDIZING PROCESS

The treatment of iron ore with aqueous HCl is in some respects independent of these considerations in that the chloridizing of the ore can be carried out with practically the theoretical quantity of acid. But it is still necessary to dry out the aqueous solutions of chlorides produced and to distil the ferric chloride out of the reaction vessel, and certain limitations on the volume of gas required for these processes will again apply.

The experimental work to determine the quantity of gas required has not yet been completed, but from the results to date there is reason to believe that it will not exceed 10 times the theoretical gas volume and may well be lower.

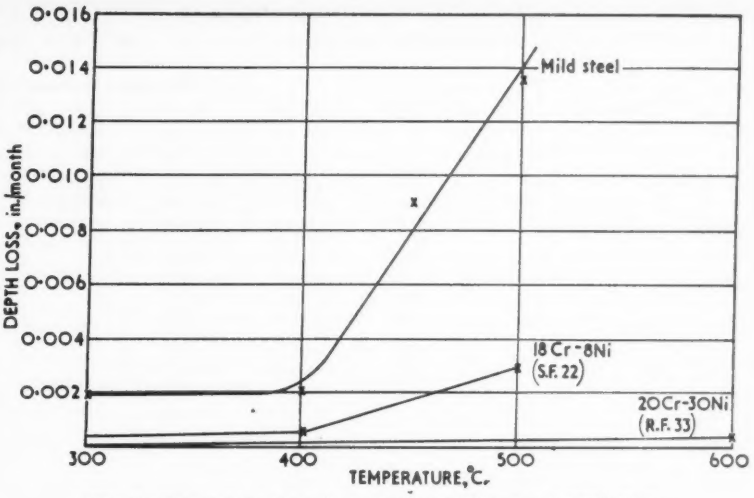


Fig. 9—Corrosion of various steels in HCl gas + 20% H_2O

VANADIUM RECOVERY

An unexpected by-product of the researches described in this paper has been the development of a number of processes for the recovery of the vanadium present in many iron ores. The Frodingham and Northants ores, as do many others, contain small percentages of vanadium, averaging usually about 0·05 wt.-%, and this normally appears in the pig iron made from these ores. Thus, the vanadium content of Appleby-Frodingham iron is about 0·12%, whilst similar percentages have been reported for German irons.

During the second World War the Germans developed large-scale processes for the recovery of this vanadium, usually via the enriched slags produced by blowing these irons in Bessemer converters. These slags were re-smelted to produce vanadium-enriched irons, which were then re-treated by a similar procedure to produce secondary slags containing up to 18% of vanadium, which are rich enough to treat for vanadium recovery by standard chemical processes.

Table IX

WATER RETAINED IN ORES CHLORIDIZED IN HCl GAS AT VARIOUS TEMPERATURES

Ore	Chloridizing Temperature, °C.	Degree Chloridized, %	Free H_2O in Chloridized Ore, %
Raw Northants	130–140	24·2	4·8
Roasted Northants ore	180	25·3	2·7
Roasted Northants ore	170–180	45·3	4·1
Roasted Northants ore	250	55·0	1·6
Roasted Northants ore	270	71·5	0·4

As opposed to these essentially thermo-metallurgical recovery processes, the author finds that it is possible to recover the vanadium direct from the ores by suitable modifications of the chloridizing processes described. It was found that if iron ores containing vanadium are chloridized in HCl gas at temperatures below that required for complete distillation of ferric chloride—say from 150° to 250° C.—the vanadium distils completely and condenses in the aqueous HCl solution in the condenser. It is probable that the vanadium is liberated as vanadium oxychloride, $VOCl_3$ (which, in the presence of water and HCl, forms the hydrated complex $V_2O_4.4HCl.3H_2O$, which is brownish in colour). This condenses in aqueous HCl to produce greenish-coloured VCl_2. This weak solution may be concentrated if desired almost to dryness, since in the presence of aqueous HCl the vanadium remains stable, but as it will be contaminated with some ferric chloride distilled simultaneously from the iron ore, the HCl process of distillation may be repeated to obtain a purer vanadium product.

Alternatively, when the initial condensate has been concentrated to a suitable degree, the ferric chloride in it may be removed almost quantitatively by extraction with suitable organic liquids, leaving behind all the vanadium as the green chloride in the aqueous acid fraction. This, on complete drying and oxidation, leaves a solid residue of vanadium pentoxide.

As already indicated, chloridizing of iron ore in the temperature range 150–250° C. is limited by certain practical difficulties. If, as is preferred, chloridizing is carried out at 300–350° C., vanadium chloride is distilled as before, but in conjunction with ferric chloride. If these vapours, plus excess HCl, are passed through to the hydrolyser under such conditions as to deposit ferric oxychloride as described on p. 32, the vanadium chloride is carried through unchanged to the condenser, and may then be treated as described above.

The vanadium recovery processes have been found adaptable to all the Frodingham, Northants, and

Table X

CORROSION TESTS IN HCl GAS + 20% H_2O (300–600° C.)

Material	Temp., °C.	Penetration Expressed as in./month after:					
		168 hr.	336 hr.	504 hr.	672 hr.	840 hr.	1000 hr.
Mild steel No. 1	300	0·0038	0·0024	0·0021	...	...	...
Mild steel No. 2	300	0·0057	0·0026	0·0023	...	...	...
Mild steel No. 1	400	0·0028	0·0020	...	...	...	...
Mild steel No. 2	400	0·0028	0·0020	...	...	...	...
Mild steel No. 1 (welded)	400	0·0011	0·0008	...	...	...	...
Mild steel No. 2 (welded)	400	0·0013	0·0009	...	...	...	...
Mild steel No. 1	450	0·0057	0·0083	...	...	...	...
Mild steel No. 2	450	0·0077	0·0101	...	...	...	...
Mild steel No. 1	500	0·0118	0·0119	...	...	...	...
Mild steel No. 2	500	0·0151	0·0154	...	...	...	...
18–8 (SF.22)	500	0·0035	0·003	...	...	...	...
20% Cr, 30% Ni (RF.33)	600	...	0·00038	0·00042	0·00034	0·00063	0·00064
RF.33 (welded)		0·00078	0·00042	0·00040	0·00025	...	...

Oxfordshire ores so far tested, together with the French ore shown in Table III. It also applies, with some modifications in chloridizing temperatures, to vanadium-containing slags such as those produced in the Appleby-Frodingham mixers and open-hearth furnaces, and to certain electric-furnace slags produced from vanadium-rich ores such as those processed in Norway and South Africa.

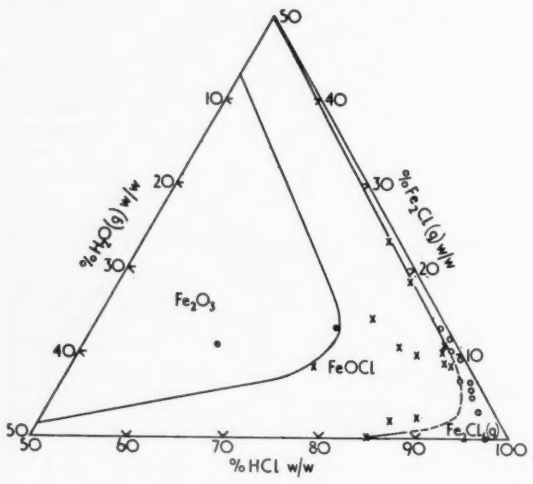
MATERIALS OF CONSTRUCTION

Before any of the processes described in this paper could be developed to anything like an industrial scale, or even to the pilot-plant scale, the question of suitable materials of construction for the reaction vessels had to be considered. At first sight, HCl gas might be thought to be an extremely corrosive chemical reagent, but a search through the literature soon indicated that this was not so, as long as the gas was dry, or, at least, above its dew point. This was confirmed in a series of experiments in which HCl gas with and without steam, and/or air additions, was passed over various metals, including mild steel, at temperatures up to 650° C. Some results are tabulated in Table X and are also summarized in Fig. 9.

These results suggest that mild steel can be used for reactors and ducts at temperatures up to at least 350° C. At higher temperatures, mild steel, brick-lined to reduce the temperature at the inner steel surface, should be suitable, whilst where direct contact with metal at temperatures over 400° C. and up to 650° C. is essential, stainless and heat-resisting steels of the type shown in Table X should be satisfactory.

Practical experience in the pilot-plant stage of development of these processes has fully confirmed these conclusions, unprotected mild steel having been found quite satisfactory for HCl gas chloridizers at temperatures up to 350° C., whilst hydrolyser shells at temperatures up to 550° C. have been constructed either of stainless steel or of brick-lined mild steel, lagged externally to prevent water condensation. The internal pipes and distribution plates at these higher temperatures have been made of Silver Fox 22 or equivalent, titanium-stabilized 18/8, with satisfactory results. The only corrosion troubles which have been encountered when using steel equipment for the processes described have arisen at positions of the equipment which have been allowed to fall below the dew-point temperature for the particular gas mixture passing at that point, resulting in aqueous acid condensation. These troubles have been overcome by jacketing the equipment at these points and heating the surfaces to some temperature above the dew point by means of steam or other suitable heat-transfer media.

Where condensation is unavoidable, glass or carbon tubes have been found to give satisfactory service. Polythene and other plastic tubes and linings have also found extensive use at such points, particularly in view of the successful welding techniques which can now be applied to many of these materials. The use of these materials is normally limited by temperature considerations.



Temperature 350° C.

Fig. 10—System $Fe_2Cl_6(g)$–H_2O–HCl

CHEMICAL ENGINEERING ASPECTS

It is not the purpose of this paper to consider fully the chemical engineering problems which have been encountered in attempting to develop the processes described to the pilot-plant stage. It is hoped to describe these more fully at some later date. It is useful, however, to summarize some of these problems briefly and to indicate the variety and complexity of the investigations which have been found necessary in attempting to transfer the chemical processes described from the laboratory to something approaching the ' shop ' scale. These include:

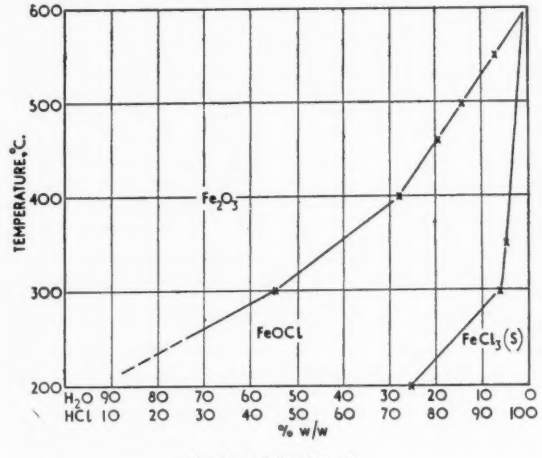
(*a*) Materials of construction—already described above
(*b*) Investigation of fluidizing techniques, e.g. fluidizing velocity of iron ore, etc., in relation to particle size distribution for all gases used in these processes throughout the temperature range described
(*c*) Design of gas distribution plates and transfer pipes, particularly in multi-bed systems
(*d*) Design of reaction vessels, including conditions for low dust entrainment
(*e*) Evaporation of aqueous HCl and chloride solutions, including the development of spray drying techniques
(*f*) Design of special instruments for measurement of bed depths and ore flows.

THERMODYNAMIC DATA

Full and reliable thermodynamic data for all the systems involved in the chemical processes described are not available.

Various attempts have been made to determine the equilibria data for reactions (1), (2), and (5). An early effort is reported by Stirnemann.[3] A much more recent attempt is described by Schäfer in a series of papers published between 1949 and 1951.[4] At first sight these latter investigations appeared to provide a complete solution to all the possible reactions involved, but the writer's experience is that they are not as quantitatively exact as implied by the author.

Mr. Thrupp, attached to the Appleby-Frodingham laboratory, has repeated some of Schäfer's work and has determined the provisional equilibrium diagrams shown in Figs. 10 and 11. It is hoped to publish a more detailed account of the methods by which these results have been obtained at a later date.



Fe_2Cl_6 gas below 1% w/w

Fig. 11—Solid phases in equilibrium with gas mixtures

SUMMARY AND CONCLUSIONS

(1) The ferric iron content of low-grade ore can be distilled almost completely as pure ferric chloride by treatment in HCl gas at temperatures of approximately 300–350° C. All other major constituents, including sulphur and phosphorus, remain in the tailings.

(2) The ferric chloride so produced can be hydrolysed by steam at 300–350° C. to produce ferric oxychloride and finally by further steam treatment at 550° C. to produce pure ferric oxide, with the regeneration of HCl gas, for use in chloridizing further supplies of ore. Alternatively, the ferric chloride can be treated with hydrogen-containing gases to produce metallic iron and hydrogen chloride.

(3) The processes described are most conveniently carried out on finely crushed ore, fluidized in a stream of reactant gases.

(4) Lime, magnesia, and manganese in the ores are chloridized to an appreciable extent and form non-volatile chlorides which remain in the tailings. The residual chlorine in these materials can be removed by treatment with steam (plus air or inert gases) at temperatures of 450–650° C. with recovery of HCl gas. These processes are assisted by the presence of silica or alumina in the tailings.

(5) Similar results to those described above can be obtained by treating ores with aqueous solutions of hydrochloric acid, followed by drying out and distillation of ferric chloride in a stream of HCl gas.

(6) Approximate equilibrium HCl/H_2O ratios have been determined by circulating mixtures of these gases over iron ore in the temperature range 200–550° C. As would be expected from the exothermic nature of the main chloridizing reaction, the equilibrium moves over to the right at lower temperatures.

(7) The rate of chloridizing of iron ores in HCl gas is retarded appreciably in the presence of the products of the reaction (viz. ferric chloride and water vapour), particularly so at about 300° C. and upwards. Nevertheless, temperatures of this order must be used for easy operating conditions, and this involves the use of fairly large volumes of gas to complete the reaction.

(8) The vanadium content of low-grade ores is distilled in HCl gas simultaneously with the chloridizing of the iron, and can be recovered finally as pure V_2O_5.

(9) The chemical engineering aspects of the processes described are briefly summarized, and in particular, materials of construction have received considerable attention. Unlined mild steel can be used in contact with HCl gas at temperatures up to at least 350° C., even in the presence of water vapour, provided that the gas mixture is above its dew point. At higher temperatures, brick-lined mild steel or stainless steel can be used.

(10) The thermodynamics of the processes described are briefly considered. Further information in this field is desirable.

PATENTS

The processes described in this paper are protected by a number of patents, some of them still pending, which have been granted both at home and abroad. The British patents already granted are Nos. 677,645; 677,690; 677,691; 677,904; 701,797; 734,080; and 734,081.

Acknowledgments

The investigations described in this paper involved the concentrated efforts of a group of chemists and chemical engineers working at Frodingham Research Department, whose enthusiasm and devoted service in support of the project are acknowledged.

Whilst it is impossible to mention everyone who assisted in this work, special reference should be made to the work of Mr. F. W. Thrupp, the senior chemist, Mr. S. A. Gregory, the senior chemical engineer, his senior assistant, Mr. J. Trees, and Mr. F. P. Reynolds, Plant Engineer. The work was guided by a small Committee under the Chairmanship of Lt. Cmdr. G. W. Wells, General Manager of the Appleby-Frodingham Steel Co., which included Mr. F. H. Saniter and Dr. J. H. Chesters, Director and Assistant Director of Research and Development, respectively. Their support and encouragement under often adverse circumstances is gratefully acknowledged.

Finally, the author's thanks are due to the Board of Directors of the United Steel Companies Ltd., for their support of these investigations, and for permission to publish this paper.

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Estimation of Temper-Rolling Reductions of Mild-Steel Sheet by an X-ray Diffraction Method

By P. W. Wright, B.Sc.,

and B. B. Hundy, B.Sc., Ph.D., A.I.M.

SYNOPSIS

The back-reflection X-ray diffraction pattern of mild steel is very sensitive to small degrees of cold-work such as are produced by temper-rolling. It is shown that by comparing the pattern from an unknown temper-rolled sample with those from samples given standard temper reductions, it is possible to estimate the temper-rolling reduction of the unknown sample. As the appearance of the diffraction pattern is dependent on the grain size of the steel, comparison must be made between samples of similar grain sizes. The method can also be used to assess the amount of roller-levelling given to sheet steel, and can be used to differentiate between temper-rolled sheet and sheet which has only been roller-levelled. Imperfect annealing before temper-rolling can be detected. In some circumstances low-angle diffraction at glancing incidence can be advantageously used instead of, or in conjunction with, the back-reflection method.

The method can be used as a periodic check on temper pass meters, and in cases when a referee method is needed to determine the temper-rolling reduction that was given to a batch of sheets. The application of this method to two industrial problems is described. 1175

ANNEALED MILD-STEEL SHEET or strip which is to be shaped by pressing or deep drawing has to be cold-worked slightly to eliminate the yield-point elongation, so that 'stretcher strains' do not occur on pressing nor 'fluting' on bending. The usual method is to give the sheet a small cold reduction (1–2%) in a temper mill followed by flattening in a roller-leveller. This reduction in the temper mill is critical because if it is too small the yield-point elongation is not completely eliminated and 'stretcher-strains' occur on pressing the sheet, and if the reduction is too high, there is a reduction in the

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Dr. Hundy, formerly a Senior Investigator at the Sheffield Laboratories of the Mechanical Working Division, is now with the Steel, Peech and Tozer branch of The United Steel Companies Ltd.; Mr. Wright, formerly an investigator at the South Wales Laboratories of the Division, is now in the Physics Department of the Association.

drawability of the sheet leading to fracture in difficult pressing operations.

The degree of temper-rolling must therefore be controlled accurately, and this is a problem that has been given much attention in recent years. Apart from the general method of measuring the elongation directly from scribed lines, a number of instruments have been developed which are moderately satisfactory. However, there is an obvious need for a method of measuring the temper of the sheet which would enable a check to be kept on the performance of mechanical skin-pass meters and on the operations of the sheet temper mill.

Such a method should also be able to determine whether an unknown sample of steel had been temper-rolled or not. Although mechanical tests could show if a particular sample had been temper-rolled, they are too dependent on factors such as chemical composition of the steel, annealing treatment, strain ageing, etc., to be completely satisfactory.

This paper describes an X-ray diffraction method which can be used to determine, by comparative means, the amount by which a steel sheet has been cold-worked. By comparison of the diffraction pattern from an unknown sample with a standard pattern it is possible to estimate the degree of cold work in the temper-rolling range to about $\pm 0{\cdot}25\%$ reduction.

CONSIDERATIONS OF X-RAY DIFFRACTION METHODS

It is well established that cold work and the concomitant introduction of internal strain in the lattice affects appreciably the X-ray diffraction patterns from metals. These various effects have been extensively studied by many investigators, and excellent summaries of their work are given by Barrett[1] and Taylor.[2]

As a result of cold working a polycrystalline metal, internal strains are introduced into each crystal of the aggregate. These microstrains take the form of lattice bending and variations of interplanar spacings over microscopic distances. This lattice distortion causes an angular spread in the reflection which renders the initially sharp spots of the diffraction pattern from the annealed sample larger and more diffuse. This effect increases with the degree of cold work until eventually the individual spots cannot be resolved with the usual techniques,[3] and the diffraction rings take on a homogeneous and diffuse appearance (apart from arcing due to preferred orientation). This is illustrated in Fig. 1 which shows the diffraction patterns from material inside and outside a stretcher-strain marking.

The greater part of the cold-work effect is due to internal microstrains, and it is easily shown[1] that the high-angle diffractions (i.e. $\theta \to 90°$, where θ is the Bragg angle) are most affected by cold work. Thus, in general, the back-reflection technique would be most sensitive to small degrees of cold-working.

Jevons[4] has made the suggestion, based on work by Goss, that X-ray diffraction would provide a simple technique for estimating the temper-rolling reduction (1–2%) of mild-steel sheet, and also points out that it is probably the only practical method for estimating the cold work imparted to a sheet by the roller-levelling process. Also Frommer[5] has given an account of a comparative method of estimating the amount of cold work, from X-ray diffraction patterns, in the case of aluminium alloys. However, the reductions used by these workers were higher than those given in temper-rolling and they also only studied the low-angle diffractions (which are least sensitive to cold work).

Back-reflection patterns are clearly indicated for the study of the degree of cold work in temper-rolled sheet, and this is confirmed by the figures in this paper. The advantages of the back-reflection technique are:

(i) For these high-angle diffractions there is large broadening of the diffracted spots for a comparatively small lattice strain

(ii) The material at any depth, from surface to centre (core), in any one sample may be examined by using a suitable technique to remove successive layers.

A transmission low-angle diffraction pattern from a sample at normal incidence cannot be obtained unless the sample is thin ($\simeq 0{\cdot}002$ in.), which usually means that the original specimen must be thinned down. Normally this thin specimen will be the central lamina of the sheet, and another specimen would have to be produced if the surface material was to be examined as well. A comparison of the back-reflection pattern from the surface of a rolled sheet sample with the corresponding low-angle transmission pattern from the central lamina of the same sample can be made from Figs. 3*f* and 2*b* respectively.

In some circumstances when the corresponding surface back-reflection patterns are fairly diffuse, e.g. when samples with small grain-size are being examined, the low-angle diffractions may be successfully employed if the side-reflection technique is used. In this, the specimen is inclined to the incident beam so that some of the diffracted rays and the incident beam are on the same side of the specimen surface. The sensitivity of this method is greatest when the specimen surface makes an angle θ (Bragg angle) to the incident beam (i.e. the diffracted rays in the horizontal plane satisfy the Bragg–Brentano condition of parafocusing). Examples of these types of pattern are shown in Figs. 2*c* and 8*f*, *g*, and *h*.

EXPERIMENTAL DETAILS

Cobalt X-radiation was used throughout these investigations. With mild-steel samples the low-angle diffraction was the $\{110\}$ ($\theta \simeq 26°$), whilst the back-reflection diffraction was the $\{310\}K_\alpha$ doublet ($\theta \simeq 81°$).

A Hilger H.R.X. unit was used in conjunction with standard Unicam cameras (back reflection and single crystal X-ray goniometer), to obtain the diffraction patterns which were recorded on Kodak Industrex D film.

When specimens are examined by either back-reflection or side-reflection (glancing incidence) methods, only the surface material contributes to the observed diffraction patterns: e.g. for the $\{310\}$ cobalt K_α diffraction from iron, 90% of the diffracted intensity arises from material within $0{\cdot}001$ in. of the specimen surface. Thus, when it was desired to

examine material at various points, from surface to centre (core), through the cross-section of the sheet, it was necessary to reduce the thickness of the sample uniformly. This uniform thinning was obtained by electrolytic polishing in a mixture of 1000 ml. acetic acid and 100 ml. perchloric acid (60%).

Electrolytic thinning was found to be the most satisfactory of several different methods that were tried, as it gave a smooth, clean, non-distorted surface even after thinning a 0·038-in. thick sample to a 0·002-in. thick central lamina. Chemical etches were not satisfactory as surface irregularities developed after prolonged etching and tests showed that reducing the thickness mechanically by polishing on emery paper introduced additional cold work into the specimen surface which affected the diffraction pattern.

EXPERIMENTAL RESULTS

Effect of Temper-rolling Reduction

Figure 3 shows the patterns obtained by diffraction from the surface of some samples of 19 S.W.G. mild steel sheet rolled on a 10 in. × 10 in. experimental mill. Increasing the reduction increases the spread and diffuseness of the pattern and it can be seen that a reduction of less than $\frac{1}{4}$% can be detected in this manner.

In normal industrial practice temper-rolling is followed by roller-levelling to flatten the sheet or strip, and tests were made to see if this treatment affected the X-ray diffraction patterns obtained from the surface of the specimens. It was generally found that roller-levelling sheet of this thickness tended to increase the diffuseness of the pattern slightly. However, with thinner sheet of 30 S.W.G. the slight amount of extra cold work imparted by roller-levelling could only be detected when the rolling reduction was less than about 0·5%. This is in accord with the fact that a smaller flexural strain would be produced in the thinner-gauge sheet for a given roller-levelling process.

Some samples of sheet temper-rolled on an industrial mill were also examined. The results are shown in Fig. 4 together with the stress/strain curves for these specimens. It can be seen that there is good correlation between the diffraction patterns and the corresponding stress/strain curves. For instance, samples *B* and *C* have similar diffraction patterns and also have similar curves showing a trace of a yield point. However, in sample *D*, the yield point has been completely eliminated and the respective diffraction pattern has become decidedly more diffuse.

Temper-rolled samples from other industrial mills were also examined by this method and similar results were obtained. The samples included 19 S.W.G. extra deep-drawing quality sheet, 30 S.W.G. tinplate strip (Figs. 6 and 8), and pack-rolled sheet.

The method can also give a measure of the efficiency of the annealing process after cold-working. One ' as received ' annealed sample showed slight traces of internal strain, as shown by the corresponding diffraction pattern, and microscopic examination confirmed that the sample was not completely annealed. Re-annealing at 950° C. and furnace cooling removed all signs of the internal strains in the diffraction pattern, and this agreed with the results of another microscopic examination. The diffraction pattern also showed that the grain size had increased (decrease in the number of diffracted spots), and this also was confirmed microscopically.

Effect of Grain Size

The grain size of a sample decidedly affects the diffraction pattern, and in fact one may obtain an estimate of the grain size from the diffraction pattern of the annealed sample.[2, 4] Thus it is necessary, for accurate estimation of the cold work, that comparison be made only between samples having approximately the same grain size. The smaller the grain size the more readily will the diffraction ring become diffuse. This is illustrated by Fig. 5 in which comparison is made between the diffraction patterns and photomicrographs of two samples of tinplate strip *A* and *B*, *A* having an appreciably smaller grain size than *B*. These patterns can also be compared with those in Fig. 3 for steel sheet of even larger grain size.

Cold Work Gradient in Temper-rolled Sheet

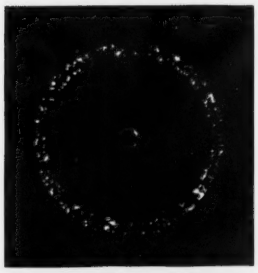
Comparing the diffraction patterns from material of various depths in temper-rolled sheet samples, it was observed that there exists a gradient of cold work. In all the cases investigated (from $< \frac{1}{4}$% to 12·25% reduction) the residual cold work, as shown by the diffuseness of the diffraction patterns, was less at the centre (core) than at the surface of the sample. A typical example is illustrated in Fig. 6.

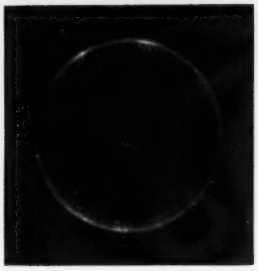
In some cases it was found difficult to distinguish visually between very diffuse patterns obtained from the specimen surfaces. This situation often arises when steel sheet of small grain size is being examined, where the diffraction patterns from the surface acquire a homogeneous and diffuse appearance after only a relatively small degree of deformation. When this occurs it was usually found possible to distinguish accurately between different specimens by comparing the diffraction patterns from the centre (core) of the sheet, where the degree of cold work (and hence the diffuseness of the patterns) was not so great. An example of this is shown in Figs. 6 and 8, in which two samples of tinplate strip, one rolled $1\frac{1}{2}$% and the other rolled $2\frac{1}{2}$%, can be compared. Visual comparison of the diffraction patterns from the surface of the samples (Figs. 8*b* and 6*a*) is made most difficult by the diffuseness of the patterns, but the difference between the samples becomes clearly evident when patterns from their respective centres (cores) are compared (Figs. 8*d* and 6*c*).

Cold Work Gradient in Roller-levelled Sheet

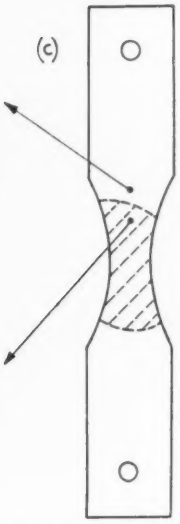
The roller-levelling process should introduce a large gradient of cold work from surface to centre with the strain increasing regularly to a maximum at the surface of the sheet. Thus with sheets that have only been roller-levelled, comparison should be made only between X-ray diffraction patterns from the respective surfaces of the samples. This is illustrated in Fig. 7

(*a*) Outside stretcher-strain marking



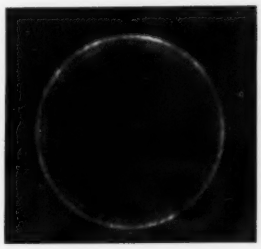


(*b*) Within stretcher-strain marking

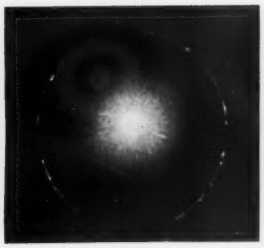


(*c*) Diagram of strip tensile-test piece after pulling showing stretcher-strain marking

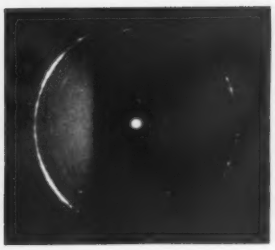
Fig. 1—Comparison of {310} diffraction patterns from mild steel



(*a*) {310} diffraction pattern (' back reflection ')



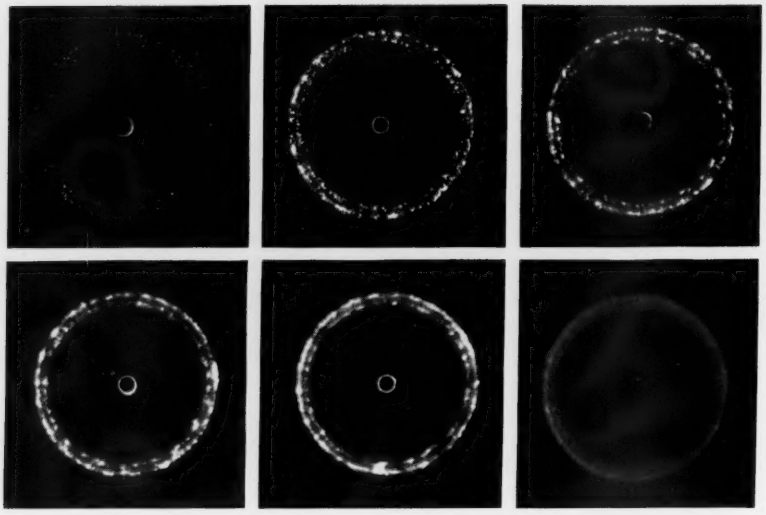
(*b*) {110} diffraction pattern. Specimen at normal incidence (' transmission ')



(*c*) {110} diffraction pattern. Specimen inclined at 26° to normal incidence (' side reflection ')

Fig. 2—Specimen of central lamina (0·002 in. thick) of mild-steel sheet sample (0·038 in. thick) which had been rolled (12·25% reduction)

(*a*) Annealed (*b*) <1% reduction (*c*) 0·7% reduction

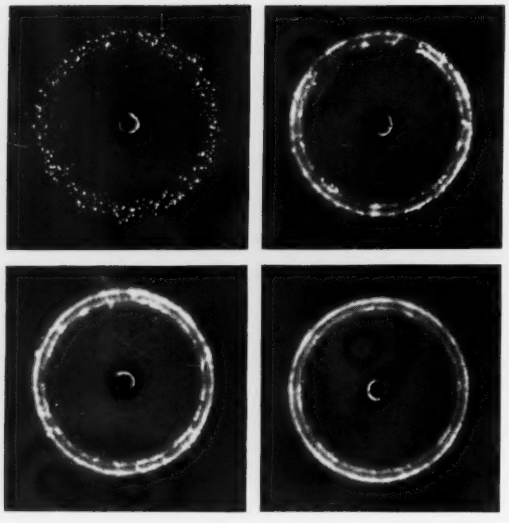


(*d*) 1·75% reduction (*e*) 3·75% reduction (*f*) 12·25% reduction

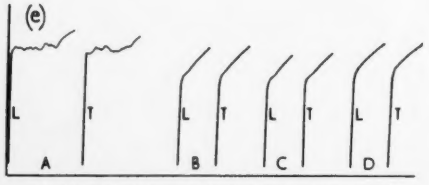
(*a*)–(*f*) Diffraction from sample surfaces

Fig. 3—{310} diffraction patterns from samples of 0·038-in. thick rolled mild-steel sheet not roller-levelled. Temper-rolling carried out on 10 in. by 10 in. experimental mill at 50 ft./min.

(*a*) Annealed (*b*) Nominally 0·55% reduction

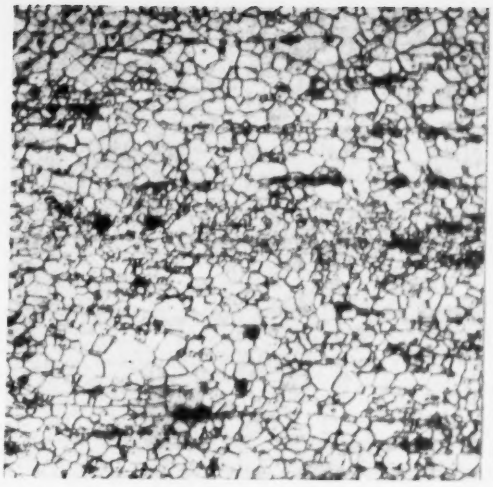


(*c*) Nominally 0·95% reduction (*d*) Nominally 1·42% reduction

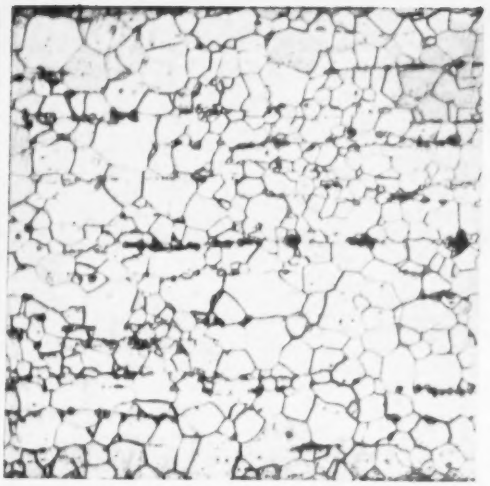


(*e*) Stress/strain curves (longitudinal and transverse)

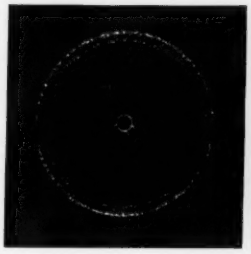
Fig. 4—Comparison of diffraction patterns from sample surfaces and stress/strain curves of industrially temper-rolled mild-steel sheet



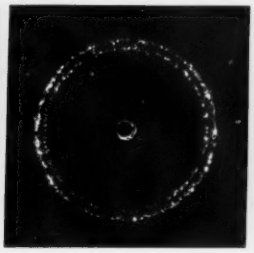
(*a*) Photomicrograph of cross-section of annealed sample *A* × 225



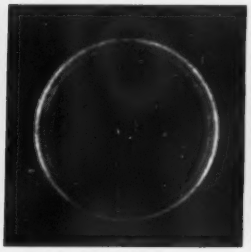
(*b*) Photomicrograph of cross-section of annealed sample *B* × 225



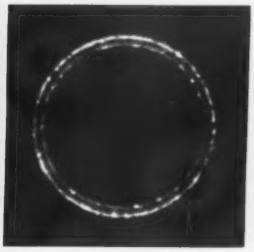
(*c*) {310} diffraction pattern from annealed sample *A*



(*d*) {310} diffraction pattern from annealed sample *B*

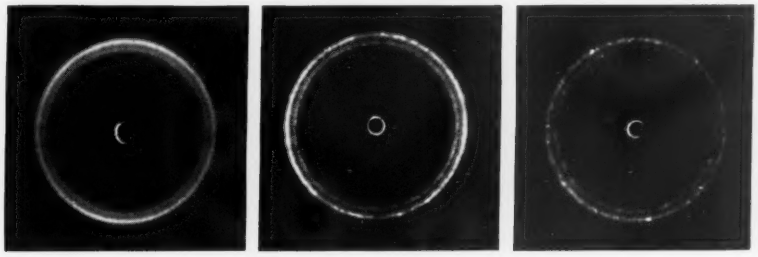


(*e*) {310} diffraction pattern from annealed sample *A* after 1½% reduction



(*f*) {310} diffraction pattern from annealed sample *B* after 1½% reduction

Fig. 5—Comparison of {310} diffraction patterns from two samples of tinplate strip (*A* and *B*) of differing grain size



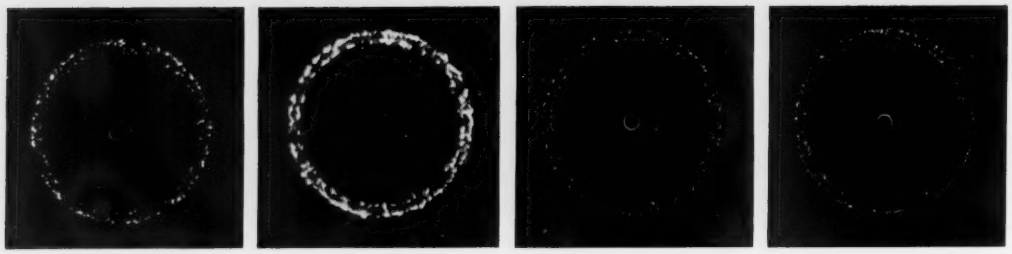
{310} Diffraction patterns from:

(*a*) Surface of sample

(*b*) Midway between surface and centre of sample (thickness electrolytically reduced from 0·0138 in. to 0·0069 in.)

(*c*) Central lamina of sample

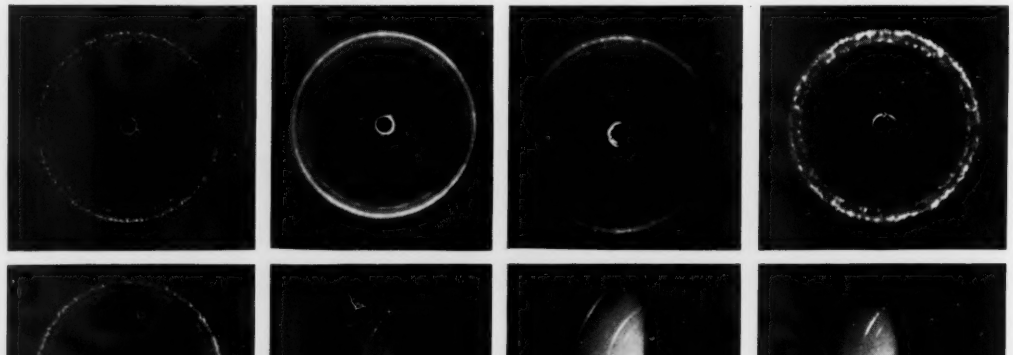
Fig. 6—Comparison of degree of cold work from surface to centre (core) of sample of industrially temper-rolled tinplate strip (0·014 in. thick). Temper-rolling in two stages on four-high mills (working-roll dia. 18 in.). Speed of rolling 2500 ft./min. Total reduction 2½%



{310} Diffraction patterns from:
(*a*) Surface of lightly roller-levelled sample (*b*) Surface of heavily roller-levelled sample (*c*) Central lamina of lightly roller-levelled sample (*d*) Central lamina of heavily roller-levelled sample

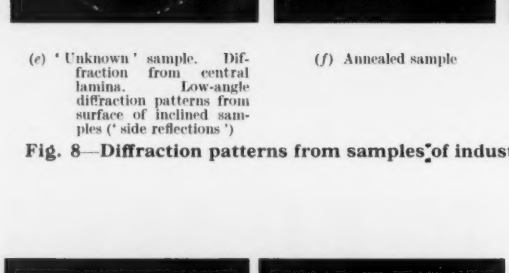
Fig. 7—Comparison of degree of cold work at surface and at centre (core) of samples of mild-steel sheet which have been roller-levelled only

{310} Diffraction patterns from:
(*a*) Annealed sample (*b*) 1½% reduction. Diffraction from surface of sample (*c*) 'Unknown' sample. (Suspected <1% reduction.) Surface diffraction (*d*) 1½% reduction. Diffraction from central lamina



(*e*) 'Unknown' sample. Diffraction from central lamina. Low-angle diffraction patterns from surface of inclined samples ('side reflections') (*f*) Annealed sample (*g*) 1½% reduction (*h*) 'Unknown' sample

Fig. 8—Diffraction patterns from samples of industrially temper-rolled tinplate strip (0·014 in. thick)



{310} Diffraction patterns from:
(*a*) Central lamina of sample *X* (*b*) Central lamina of sample *Y*

Fig. 9—Examination of two samples (*X* and *Y*) of mild-steel sheet from two portions of coil which received nominal 1% temper-pass. *X* received a definite 1% reduction (corresponding elongation measured) and showed no yield point in stress/strain curve. The precise reduction of *Y* was unknown but the stress/strain curve showed a slight yield point.

where it is seen that whilst the patterns from the surfaces of the light and heavily roller-levelled sheet differ greatly, there is only a very slight difference between the diffraction patterns from the respective central sections (cores) of the samples. This figure also shows that there is practically no residual cold work at the centre of a sheet which has only been roller-levelled. This feature, as shown by X-ray diffraction, would enable temper-rolled samples to be distinguished from those which have been roller-levelled, since cold work is plainly detectable at the centre of a temper-rolled sample.

Effect of Ageing

The physical properties of temper-rolled steel sheet are known to change radically when it is aged (either at room or higher temperatures) after rolling. Therefore we might ask whether strain-ageing would affect the X-ray diffraction patterns.

Tests on specimens temper-rolled variously and aged at several temperatures showed that ageing at low temperatures (up to 100° C.) did not discernibly affect the pattern. Heating a specimen (temper-rolled 3%) at 200° C. and above, however, seemed to give some reduction in the spread of the diffractions from the deformed areas; this was probably due to recovery occurring in steel at these temperatures.

APPLICATION

From the above results it is evident that the back-reflection X-ray diffraction pattern is very sensitive to the small degrees of cold work such as are produced by temper-rolling. Thus, by comparing the X-ray diffraction pattern from an unknown sample with those from samples of the correct grain size having standard temper-rolling reductions, it should be possible to estimate the degree of cold work accurately. The method is obviously too tedious to be used for everyday production control but it could be very useful for occasional checks on works practice and also for sorting one batch of material from another. To illustrate the possible applications of the method to industrial problems, two cases where it has proved useful will be quoted.

A composite coil of a deep-drawing quality steel was temper-rolled to a nominal 1% reduction, using a mechanical temper-pass meter. On testing, it was found that some parts of the coil showed a small yield point compared with the smooth stress/strain curve of the remainder of the coil. It was thought that this part of the coil had not been rolled to the same extent as the rest and a check was made using the present method. A sample cut from the suspect part of the coil was examined together with a sample from the same coil that had definitely been given a 1% reduction. The X-ray diffraction photographs (Figs. 9*a* and *b*) from the central sections (cores) of the samples showed that, as expected, the suspect portion of the coil had not been cold worked to the required temper-rolling reduction. In this particular case only a very slight difference could be detected in the diffraction patterns from the *surfaces* of the two samples.

In another case it was doubtful whether a batch of tinplate strip had been temper-rolled by the requisite amount (1½–2½%). It was found to be faulty in that fluting had occurred on forming. It was suspected that this particular batch of tinplate had not been temper-rolled at the main works but had been despatched in the annealed condition to a neighbouring works where it had given only a slight cold reduction (< 1%) before hot tinning. Standard samples temper-rolled 1½% and 2½% reduction and an annealed sample of the same material were supplied together with a sample of the suspect strip. These samples were compared using back-reflection and side-reflection X-ray diffraction photographs (Fig. 8). The results showed clearly that the suspect sample had received only a slight reduction and had therefore not been temper-rolled at the main works.

CONCLUSIONS

(1) The degree of temper-rolling of mild-steel sheet can be estimated accurately by comparing the back-reflection X-ray diffraction patterns from the sample under examination with those from samples given known standard temper-rolling reductions.

(2) The degree of diffuseness of the pattern, due to cold work, is dependent on the grain size of the steel, and therefore comparison should only be made between steels of comparable grain size.

(3) The method shows that the surface of temper-rolled sheet is worked to a greater extent than the centre (core) of the sheet. For this reason, when the surface patterns are too diffuse, it is sometimes easier to estimate the degree of cold work by studying the diffraction pattern from the central laminæ of the samples.

(4) With samples which have only been roller-levelled, there exists a gradient of residual cold work which increases regularly from the centre (core) of the sheet to a maximum at the surface. Very little cold work can be detected at the centre (core) of a roller-levelled sample. This feature enables temper-rolled sheet to be distinguished from purely roller-levelled sheet.

(5) A glancing incidence (' side-reflection ') technique can sometimes be used to advantage when the grain size of the steel is small.

Acknowledgments

We thank The Steel Company of Wales Ltd. (Trostre and Margam Works), John Summers and Sons, Ltd., Whitehead Iron and Steel Co., Ltd., and the Glynhir Tin-Plate Works, who supplied the materials for this work, and also Mr. D. Luther Phillips for his encouragement and helpful counsel.

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Steelmaking at Redbourn

By S. R. Isaac

SYNOPSIS

The paper briefly reviews the development of the Redbourn works of Richard Thomas and Baldwins Ltd. over the past thirty years. A detailed survey is made of the layout, equipment, and operation of the present melting shop, with particular reference to the all-basic open-hearth furnace, which was pioneered at Redbourn, and to the new desiliconizing plant. 1199

ALTHOUGH there has been a Redbourn Works in existence in the present location since 1874, it was not until the latter part of 1918 that the production of steel started on the site. The plant operating under the name of The Redbourn Hill Iron and Coal Co., Ltd., had previously consisted of blast-furnaces, which drew their supplies of Frodingham ironstone from the nearby quarries.

During the first 34 years of their activities, these blast-furnaces were owned by a few shareholders with local interests, and the iron produced was available to the iron market generally. In 1906, however, control of the works passed to the late Mr. Frank Treherne Thomas, who was then Chairman of the Cwmfelin Steel and Tinplate Co., Ltd., with headquarters at Swansea; thus began Redbourn's association with the great steelmaking organization of which it now forms such an important part.

In 1916, the owners, after consultation with the Ministry of Munitions, decided to extend the works so as to produce some of the extra steel required for war purposes. Two batteries of coke ovens together with a melting shop and rolling mill were designed, and the erection of these proceeded simultaneously. The first of the four steel furnaces was ready for production in October, 1918, and the other three came into operation at varying intervals thereafter. The 1918 armistice occurred very quickly after steel production began and the steelworks were therefore affected by post-war conditions very early in their existence.

In 1918, the Cwmfelin Steel and Tinplate Co., Ltd., was amalgamated with Richard Thomas and Co., Ltd., and seven years later the Redbourn Hill Company was put into voluntary liquidation, its assets and liabilities being taken over by the parent company, Richard Thomas and Co., Ltd., which operated under that name until January, 1945, when, on the amalgamation with Baldwins Ltd., it became known as Richard Thomas and Baldwins Ltd.

Very little development work was undertaken until after the inauguration of the Import Duties Advisory Committee in the early 1930's.

STEELMAKING PRACTICE

The Melting Shop

The melting shop, as then put down, consisted of four 60-ton fixed open-hearth furnaces and a 300-ton mixer, all producer-gas fired. There were, however, some special features of this shop which are worthy of mention, particularly in view of later developments which have brought the melting shop to its present position.

The first notable feature is the single-span building covering the open-hearth furnaces and the casting pit, instead of the conventional double-span building. Also worthy of mention are the cranes put up to serve the then 60-ton furnaces: on the charging side there are two 100-ton hot-metal cranes and on the pit side two 160-ton teeming cranes. Add to this the very liberal space between furnaces, regenerator, flues, valves, and chimney sizes, none of which has been enlarged to date, and one can clearly see the foresight of the late Mr. Frank Thomas, father of the present General Manager, who was responsible for putting down the plant.

Between 1918 and 1933 the plant had a very chequered experience, with a number of long periods of idleness. Since 1933 the plant has been in continuous operation and over this period has made a material contribution to the development and improvement of open-hearth technique in the U.K.

The shop was enlarged firstly by the addition of two more furnaces and finally by a new 500-ton mixer placed in a separate building, the old mixer being taken down and a seventh furnace put in its place. In addition the capacity of the furnaces has been increased, first to 85 tons, then to 100 tons, and now to 120 tons capacity. At present, therefore, the shop consists of seven fixed basic O.H. 120-ton furnaces and one 500-ton mixer. Sufficient 120-ton casting ladles are, however, not yet available, and so 30% of the charges are still limited to 100 tons. This position will be rectified before the end of 1955, when all furnaces will be charged for tapping 120 tons.

The general layout of the shop is given in the symposium published by this Institute in 1938.*

Fuel Supply

Over the years much pioneer work has been done at Redbourn in developing the use of coke-oven gas

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Mr. Isaac is Melting Shop Manager of the Redbourn Works of Richard Thomas and Baldwins Ltd.

* S. R. Isaac, "Symposium on Steelmaking," Spec. Rep. No. 22, pp. 111–115: 1938, London, The Iron and Steel Institute.

for firing the furnaces. Many were the trials experienced in the early days of firing with coke gas, but these were eventually overcome, and today the standard practice is to fire with coke gas using pitch creosote as an illuminant. Up to the early part of the war crude tar was used as the illuminant; then it was announced that with the great demand for toluene crude tar could no longer be used, and pitch was offered in its place. This presented too great a problem for a quick conversion, and so, following a discussion with the control, pitch creosote mixture was adopted as a compromise. This only involved the use of additional steam heaters and the lagging of a steam tracer with all the mains.

It was quickly appreciated that pitch creosote gave more luminosity than crude tar; in fact in all ways it was a more efficient fuel. For many years Redbourn was the only works using this fuel on open-hearth furnaces. The proportion of pitch creosote used varies considerably, the aim being to use up all the coke gas available, using only sufficient pitch creosote to give the necessary luminosity.

Any deficiency in coke gas is in the first place made up by increasing the pitch creosote, but on occasions, when the deficiency is more than can be covered with the available pitch creosote, fuel oil is brought in. The quantity of pitch creosote used varies from 15% to 40%. A very noticeable feature is that the higher the percentage of pitch creosote used, the lower the heat content in B.t.u. per ton of steel. When fuel oil has to be used, the use of part oil and part gas is preferred to putting one furnace completely on oil, as much better results are obtained using oil plus gas than with straight oil firing.

Up to a year ago the gas was supplied to the furnaces at a pressure of about 20 in. W.G. and put into the furnace through a 4-in. burner. For a long time this pressure was thought too low, and recently experiments were made with a new fan, boosting the pressure up to 60 in. W.G. and reducing the burner to $2\frac{5}{8}$ in. So beneficial were the results that all the furnaces are now being changed over to high-pressure (60-in. W.G.) boosters. Coke gas at this pressure plus 15% pitch creosote gives a melting rate well in excess of the charging rate. However, new charging machines are on order, and if and when it is found possible to bring the charging rate up to or above the melting rate, the use of combustion oxygen will be considered. At the moment it is felt that there is no benefit to be obtained from the use of oxygen for combustion.

The coke gas used contains 7 grains of sulphur per cu. ft. which can and does give some extra sulphur pickup. The question of desulphurizing the gas is being considered, and should be applied in the not too distant future.

All-basic Furnaces

Redbourn has made a substantial contribution to the development of the all-basic furnace. At the outbreak of the last war two complete all-basic furnaces were in operation and a third was being converted. War conditions brought this work to a close, but again after the war, two all-basic furnaces were built and the work continued.

The results with all-basic furnaces leave no doubt about the increased rate of working that can be achieved. There were at Redbourn, however, a few snags. First and foremost was the slag pocket capacity, which is the most serious source of delay now that the furnace capacity has been increased to 120 tons. This necessitated the furnace coming off for the pockets to be cleaned out about every 14 weeks.

Heating up with big heavy partly worn basic roofs was found to be a difficult task; although, by taking it very steady, it could be done, the time taken reduced furnace availability and thus reduced the benefits of the increased rate of production. A further factor, of course, was the high cost of all-basic roof bricks. As a result a compromise has been reached: all the furnaces have been built with complete basic uptakes and ends, all-basic back and front linings, and a 42-ft. silica roof over the bath. This combination gives the best all-round refractory cost and permits a good furnace availability (about 90%) to be maintained. The present aim is to run these furnaces at maximum capacity and get 12–14 weeks run from the silica roof, and then throw a new silica roof over. This can be done fairly quickly: the time from tapping the last charge in the old roof to tapping the first off the new roof is about 40 hr. It is hoped to reduce this time in the near future by using light alloy centres in place of the wooden centres now used. For carrying out a repair of this sort the procedure at Redbourn is to fettle after the last charge, charge sufficient scrap, limestone, and ore to bring the bath up to sill level, plate over with old sheets, and then, putting in as many charging pans as possible, drop the old roof. In this way cleaning can largely be effected while the roof is being put on, under more comfortable conditions than with an empty bath. The repair and cleaning out completed, the damper is put in for about 2 hr., which is sufficient to bring the roof temperature above the spalling point. The furnace is then lit up and gas is kept on both ends. This, with reversing every 10 min., soon brings furnace and regenerators up to normal working temperature.

Hearths

The maintenance of the hearth on basic furnaces is of vital importance in regard to both output and quality of steel made. Much attention has therefore been given to this subject and various materials and methods of making the hearth have been tried out. Dolomite rammed with tar or burnt in, Basifirm burnt in, and magnesite burnt in have all in turn been tested. For a period satisfactory results were obtained with all three, but after about two years all these types came to the position where heavy bottom boils, when refining was followed by long and heavy fettling periods, had a bad effect on the steel quality and also on outputs. This led to the conclusion that two years was long enough for any basic hearth, but the great disadvantage was that it added anything from a week to ten days to the time of a general repair if the old hearth had to be removed and a new one put in. Since this amount of time could not be spared, hearths were made to last anything up to ten years; there was a considerable loss of production through time taken over flowing and fettling, a process very arduous to the workers, and a number of charges

broke away and became a complete loss, as well as involving a lot of labour in cleaning up the scrap made. It is not surprising, therefore, that the opportunity to try out a graphitized hearth was eagerly taken when this material was made available.

For the first trial on this material the brick sub-hearth was dispensed with, the bottom being lined only with one course of ordinary firebrick. The remainder of the hearth was rammed entirely with graphitized dolomite. For fifteen weeks this hearth was satisfactory, except for a tendency to grow in front of the taphole. This was hard to understand until, in the fifteenth week, the furnace broke away in this spot and put the charge on the floor. The furnace was taken off and the hearth removed carefully. This provided the answer: the great thickness of dolomite at each end was contracting slightly after each tap and, instead of moving back on heating up, was pushing up the centre, causing a hollow spot underneath. However, disappointing as this result was, it was felt there was a future for this type of hearth.

For the next attempt the sub-hearth was bricked in the normal way, most of the shaping being done in the brickwork. Over this was put about 1 in. thickness of Doloset to give the whole a smooth surface and even contour. On to this was rammed a uniform 9 in. of graphitized dolomite. The whole of the bottom and a bulk of the front (charging side) bank was put in, in one ramming, the back bank and top of front bank being rammed inside wooden supports in the usual way. This is certainly the best hearth tried to date, and all seven furnaces have now been working on these hearths for some few years. The wear on the slag line is still considerable but there is rarely a hole to rabble and there are almost no bottom boils. One of the reasons for this is undoubtedly that a hearth is now never kept in above two years. Owing to the very slight absorption of slag or metal into the hearth, the hearth can be removed with very little disturbance of the brick sub-hearth in less than 24 hr. and another rammed in less than 24 hr. Thus, by planning a repair with bricklayers, a hearth can be renewed by adding not more than one day to the normal time for a general repair, and consequently a hearth is never allowed to stay in more than two years.

Raw Materials

The melting shop was put down to convert the pig iron made into steel and, whilst the melter's right to grumble at the quality of iron supplied has not been waived, no effort is spared to do the job, whatever the quality of the iron.

Pig iron forms the basis of the charge, and the furnaces work with 65–70% hot metal and 30–35% scrap. Unfortunately the blast-furnaces are not supplied with sinter, but work on a mixture of local ore plus Northamptonshire with a little foreign ore. Under such burdens with low-grade ores, the pig iron, as might be expected, varies greatly in analysis. However, in the not far distant future Redbourn should be working on a sinter burden and, like its neighbours, making a pig iron more regular in quality.

The hot metal is desulphurized with ¾% soda ash, skimmed, and put into the mixer. This is very effective, and there is no trouble in supplying the furnaces with low-sulphur iron. There is, however, one big disadvantage. Should the metal be cold (and high-sulphur iron generally is), then despite the fact that the iron has been desulphurized high-sulphur melts are obtained in the open-hearth. This is attributed to a greater pickup of sulphur from the gas when working with a cold iron. Up to date fluctuations in silicon have been considered to be more detrimental to production than fluctuations in sulphur.

At the time of writing a new desiliconizing plant is being started up. The object of the plant was to allow the blast-furnaces a little more margin in silicon in the hope of getting a hotter clean iron lower in sulphur, and in order to remove the silicon with oxygen and at the same time increase its heat, thereby speeding up the melting and refining time in the open-hearth. The first few days' results are very promising, but not enough data are available to allow figures to be quoted. However, the results will be published with the discussion on the paper in a later issue of the *Journal*.

Scrap—Each year scrap quality gets worse from a charging standpoint, and the time is long overdue for scrap merchants to get down to the job of preparing scrap for the ever increasing melting rates of modern furnaces.

Limestone—All the limestone used is a local product. Of a soft chalky nature, it works very well and is very easily fluxed.

Lime—Lime supplies are received from a number of sources, none of which is wholly satisfactory, since rarely does it contain less than 0·2% of sulphur; 0·3% and even 0·4% is often met with. The solution appears to be to burn lime in the works with clean blast-furnace gas, a proposal which has been under consideration for some time.

Ore—All the ore used on the furnaces is Swedish Kiruna C.2, containing about 0·5% P.

Products

Over the last ten years the product of Redbourn has steadily changed from mainly billets of varying specifications to mainly rimming steel (0·06% C max.) for tinplate and sheet. This in turn has considerably increased the burden on the open-hearth plant. In the billet days when the iron went off quality production rates could be maintained by increasing the tonnage of free-cutting steels.

Today 5000–5500 ingot tons per week are made into 0·06% C rimming steel, rolled into slabs, and sent to Ebbw Vale for rolling into strip. A further 1500–2000 tons of similar quality is rolled into billets or narrow slabs for further processing into narrow strip. About 500 tons of high-silicon steel for transformers is also made. Part of this is for hot-rolled sheets and part for oriented sheets. This clearly indicates the increased burden put on the shop.

Instrumentation

Although the shop was built in 1918 without provision for any instrumentation on the furnaces, a reasonable attempt has been made to assist melters by the provision of the following instruments:

(i) Gas-flow recorder
(ii) Liquid fuel (oil or pitch creosote) recorder
(iii) Air recorder
(iv) Furnace pressure indicator and automatic damper control
(v) Roof-temperature recorder
(vi) Bath-temperature indicator and recorder for immersion pyrometers.

Furnace Operation

There is nothing exceptional about the method of operating at Redbourn. As previously mentioned, one of the present sources of delay is charging. Charging time varies considerably, depending on the nature of the scrap and the number of furnaces charging. No solution has yet been found to the problem of bunching.

The scrap, limestone, and ore are charged in layers, keeping the oxide well down but not on the bottom. The fuel carried during charging varies with charging rate, the aim being to maintain maximum roof temperature all the time.

When all the cold materials are in it is preferred to have the scrap well running before adding the hot metal in an effort to get a good flush slag off. For 120-ton charges 14 tons of limestone and 3–10 tons of ore are charged, depending on the silicon content of the hot metal. With reasonably hot metal a good flush slag is obtained, but with poor-quality hot metal, when a better flush slag would be preferred, little or none is obtained. No feeding is done when melting unless very-high-silicon metal is being used, when some lime would then be fed.

Since the iron from the blast-furnaces may vary from 0·4% to 2·5% silicon and from 0·05% to 0·30% sulphur, there is a wide variation in the melts, and in consequence a wide variation in refining time. The specification for most of the steel produced is 0·06% C (max.), 0·035% S (max.), and 0·02% P (max.). Phosphorus presents no trouble, as the bulk of slag necessary to give the 0·035% S is far more than enough to look after it.

Refining is therefore purely a question of making sufficient slag to ensure a 0·035% max. sulphur content. The charge is therefore worked with additions of lime and spar (and some oxide if carbon is high) till the sulphur is reduced to within the range of 0·035% max. To ensure 0·035% max. of sulphur it is unwise to exceed 0·35% S in the slag. The amount of lime fed would average 8 tons, varying on good and bad melts from 5 to 14 tons.

With bad melts with, say, 0·12% S to start, this is a slow and tedious task, but it is the only sure way,

Table I

A CHARGE FINISHED WITH OXYGEN ONLY

Fuel input progressively reduced to quarter of normal from 12.10 to 12.27

Time	C, %	S, %	P, %	Mn, %	Fe in Slag, %	Temp., °C.	Remarks
12.00	0·22	0·027	0·020	0·075	22·0	1550	Bath in cold condition
12.03							1 lance (2850 cu. ft. of oxygen)
12.10						1558	
12.15	0·065			0·075	22·0		1 lance (3330 cu. ft. of oxygen)
12.22						1594	
12.27	0·035			0·065	27·0		1 lance (2550 cu. ft. of oxygen)
12.32						1613	
12.35							1 lance (2130 cu. ft. of oxygen)
12.40						1620	
12.55	0·024	0·021	0·010	0·055	29·0		1 lance (600 cu. ft. of oxygen)
1.00						1608	Furnace tapped

Approximate Cost and Time Comparison

Finishing with Oxygen	£ s. d.	Finishing with Swedish Ore	£ s. d.
12,000 cu. ft. oxygen at 12s. 6d. per 1000 cu. ft.	7 10 0	2 tons ore at 114s. per ton	11 8 0
100 ft. of 1-in. gas pipe at 6½d. per ft.	2 14 2	30,000 cu. ft. of CO gas at 1s. 4d. per 1000 cu. ft.	2 0 0
		50 gal. pitch creosote at 6·72d. per gal.	1 8 0
	10 4 2		14 16 0
Saving: £4 11s. 0d.			
Time to remove 0·22% down to 0·024% C	1 hr.	Average time taken to remove 0·22% down to 0·03% C	2 hr. 30 min.
Saving 1½ hr.			

It is not possible to estimate saving in refractory cost on one charge, but the roof under ore finishing was frequently running, since it had to drive fuel into the furnace to maintain heat. Under oxygen finishing it very rarely reached over 1580° C.

Table II

A TYPICAL CHARGE WORKED WITH OXYGEN AND ORE

Time	C %	S, %	P, %	Mn, %	Fe in Slag, %	Temp., °C.	Remarks
9.40	0·23	0·032	0·020	0·12	9·0	1586	
9.43							15 cwt. ore and 1 ton lime added
9.47							5400 cu. ft. oxygen
10.00	0·075	0·032	0·013	0·09	13·0	1590	
10.05							15 cwt. ore added
10.08							4200 cu. ft. oxygen
10.17	0·030	0·031	0·012	0·065	16·0	1600	
10.20							Furnace tapped

and its success is proved by the fact that 85% of the steel made is tapped well under the 0·035% S level. The time taken in refining varies from 2 to 6 hr.

Removal of Carbon

Up to late 1953 carbon was removed by additions of oxides (i.e. scale or Swedish ore) and to get down to 0·06% C max. (and in some cases to 0·029%) took an appreciable time by this method and caused fairly heavy wear on the furnace, which had to be maintained at top heat. In November, 1953, the use of oxygen was therefore tried for reducing the carbon. So successful were the results that it was decided to run a 4-in. oxygen pipe through the shop with a downpipe to serve each furnace. Table I gives details of this first trial.

At present it is standard practice once the sulphur is brought under control to eliminate the carbon with small additions of ore and blowing with oxygen. Table II is a typical example of eliminating carbon in this way.

Since oxygen has been piped on tap for the furnaces, much more experience has been gained in its use, which may be summarized as follows:

(i) The quickest way to reduce carbon is by addition of ore followed by blowing oxygen

(ii) Sulphur must be removed before blowing oxygen unless carbon is above 0·30%, when some oxygen may be used to reduce carbon to about this level

(iii) Very low carbon contents can be obtained with very much lower iron contents in the slag by blowing oxygen

(iv) The increase in temperature of the metal after blowing permits a reduction in the fuel input and thus enables the roof temperature to be kept well under 1600° C., even when making 0·029% C max. steel.

Many other uses have been found for oxygen, such as blowing steps from tapholes, removing metal from any holes in bottoms, and, in cases of trouble, assisting to melt a charge or bring its temperature up to tapping heat.

Those interested in the use of oxygen for refining are referred to a paper by one of the author's assistants, Mr. S. Barker, on the advantages of the use of oxygen in fixed open-hearth furnaces, read before the Lincolnshire Iron and Steel Institute.*

* This paper has been submitted to The Iron and Steel Institute for publication in the *Journal*.

Outputs

Over the last few years the output of the shop has steadily increased. Last year was the highest to date when 396,081 ingot tons were made. This year to date (23rd July) 228,293 tons have been made, and there is every hope that the year's output will reach 450,000 tons.

Pitside Practice

All the steel now made at Redbourn is top-poured into narrow-end-up moulds. Two sizes of mould are in use: a 3-ton square mould and a 5-ton slab mould. By far the biggest problem in the casting bay is the handling and disposal of the slag. As about 30% slag is made, this is a formidable task. However, with the introduction of a desiliconizing plant it is hoped that there will be a fair reduction in slag volume; if and when the gas is desulphurized, a still further reduction in slag volume should result.

A sad feature of this large volume is that when very low-carbon steels are being made, this slag has as much iron in it as the local ore, but it is, of course, too high in phosphorus to be suitable for return to the blast-furnaces. However, it is possible that one day there will be a Bessemer plant in the area, in which case this slag could form a valuable addition to the blast-furnace burden.

CONCLUSION

This paper has not gone into highly technical details, but has been designed to show that despite the poor quality of the raw materials available compared with those used in the U.S.A., or even at U.K. plants working with foreign ore, high-quality steel can be made at Scunthorpe in sufficient quantities to help maintain the high production required to meet the ever-increasing demands for British steel.

Acknowledgments

The author would like to place on record his appreciation of the co-operation he has always received at Redbourn from all the staff and the workmen, particularly the melters, who have at all times been most willing to co-operate in any experiment. He is also grateful to the General Manager, Mr. C. T. Thomas, for permission to publish this paper.

British Iron and Steel Research Association

COMMITTEE ORGANIZATION CHART *at June 1st, 1955*

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A Burden
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AA Roll design conference
B Solid mechanics group
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E Sheet metal working
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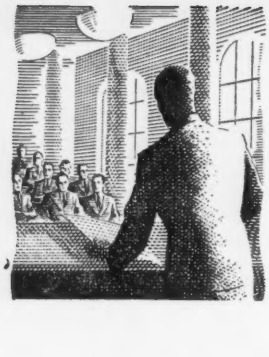
F Forging

PE PLANT ENGINEERING

I Blast-furnace and ore preparation plant
A Furnaces and fuel
R Rolling-mill plant
H Mechanical handling plant
N New engineering techniques

MG METALLURGY GENERAL

K Structural engineering steels
H Electrical sheet
HA Electrical sheet analysis
L Tool steels
J High-temperature steels (*joint with E.R.A.*)
JA Scaling of steels at high temperatures
A Alloy steels
M Fatigue and inclusions
N Thermal treatment
NA Isothermal transformations and hardenability
D Methods of analysis
DA Raw materials and slags
DB Iron and low-alloy steels
DC High-alloy steels
DD Spectrographic
DE Physico-chemical
O Castaing micro-analysis technique (*joint with B.C.I.R.A., B.N.F.M.R.A., and B.W.R.A.*)
B Corrosion
BA Protective coatings
BB Atmospheric corrosion
BD Waters (corrosion)
BE Corrosion of buried metals
BF Methods of testing



DISCUSSION ON PAPERS

Discussion at Meetings · Written Contributions

AUTUMN GENERAL MEETING, 1954

The AUTUMN GENERAL MEETING of THE IRON AND STEEL INSTITUTE was held on Wednesday and Thursday, 17th and 18th November, 1954, at the Offices of the Institute, 4 Grosvenor Gardens, London, S.W.1. The President, the Hon. R. G. LYTTELTON, was in the Chair.

Morning and afternoon sessions were held on both days, and reports of two sessions are printed below. The remainder will be published in later issues of the *Journal*.

DISCUSSION ON THE FUTURE OF STEEL MELTING

This discussion was based on the paper by Professor M. W. Thring (Sheffield University) entitled **"The Future of Steel Melting,"** which appeared in the April, 1954, issue of the *Journal* (vol. 176, pp. 424–432). Professor **Thring** presented his paper.

Mr. **J. Mitchell,** C.B.E. (Stewarts and Lloyds, Ltd.): I have long been an admirer of the experimental work which Professor Thring and his associates have carried out on O.H. design and of the theoretical picture which they have evolved from that work, but I am afraid I cannot stretch my admiration to include this present paper. Indeed it recalls to me the remark of Oscar Wilde's on hunting—' The unspeakable in pursuit of the uneatable.' Here we have the unworkable in pursuit of the unattainable. The author has stated clearly some of the disadvantages, both thermal and metallurgical, of the modern O.H. furnace, but he has failed to appreciate that there are alternative methods of steelmaking and that it might well be with these that the future lies.

I do not want to lay myself open to the charge of being an old diehard, but I must say that this sketch of materials being pushed down the ramp by a ram made me shudder. It requires no lively imagination to see what is bound to happen in this part of the system. The mass of scrap at the bottom is going to be tacky and that above it plastic and compressible, whilst the incoming cold scrap will be pushed in amongst the earlier heated material. Surely this must be regarded as impracticable. The only portion of the O.H. charge which might be amenable to this melting-down system would be cold pig iron, but how many furnaces in the future will be using this material ?

The author has made a great point—and rightly so—of the advantages to be derived from a thin slag and shallow bath, but I submit that these are purely illusory unless there is an intimate contact between the slag and metal. This is precisely what will not happen unless there is a considerable percentage of iron in the charge.

I accept the disadvantages of the O.H. process which the author listed, and especially the limit of attainable thermal efficiency. I suggest there is only one way to overcome these, namely, to generate the heat in the metal itself instead of trying to push it through the slag. The process in which this is done is, of course, the converter process, and, with the new oxygen techniques, a superheat in the metal makes it possible to use 30–40% of scrap. On our present knowledge this seems to suggest that some form of a converter process is a likelier development in the future than open-hearth variations of the kind described in this paper.

Dr. **A. H. Leckie** (Iron and Steel Board): I still have some belief in the Siemens type of O.H. furnace. We must examine the author's paper very carefully because, if his suggestion that the Siemens furnace is no longer the right melting furnace is correct, the development plans of the steel industry will need some substantial modifications.

Why is it that the Siemens furnace, which is now 100 years old, is still the most important steelmaking unit in many of the major industrial countries, and even in the U.S.A., where there is always a great readiness to try anything new ? I do not think that the steel industry is particularly backward in its ideas, and I submit that the Siemens furnace is still with us because it is the best

for its particular job. I do not question Mr. Mitchell's statement that converter processes are equally good, but I am thinking of cases where it is necessary to deal with much scrap. The author is not fair to the Siemens furnace, because he has not discussed one or two of the subsidiary points which make it better than theory suggests.

The main difficulty is that it is necessary to send a great deal of high-temperature heat out of the working chamber, and regenerators can recover only part of this. Most modern O.H. furnaces, however, have waste-heat boilers as well as regenerators. The theoretical efficiency of the best possible Siemens furnace equipped with the best possible waste-heat boiler would be nearer 65–70% than the 50% maximum given for this furnace in the paper. I do not suggest that the heat recovery potential of the waste-heat boiler should be used to excuse inefficiency—we want to make steel, not steam, as the author says—but there will always be a steam potential, and that should be taken into account when considering fuel saving, just as when working out the efficiency of a blast-furnace we do not stop at the gas going out of the top but take into our calculations the credits from the gas.

The author has been too favourably predisposed to the counterflow system. No account has been taken of the heat required to melt the slag-forming material. In making steel from the kind of pig iron which we get here, the slag bulk is often about 20%. The heat required to melt fluxes is about 50% more per unit weight than the heat required to melt steel, and this item would make a difference to his calculations.

He has allowed for leakages, but so far as I can see all that he has done is to allow for 20% of excess air; his furnace, which has a high stack full of scrap, is going to need suction at the top, or pressure at the bottom, to make it work, so that there are bound to be some leaks or blow-outs, and that may make an appreciable difference to the calculations. I think that water-cooling will be needed, so that after all these additional heat losses the efficiency may not be quite so good as he says.

These criticisms so far are all of a physical engineering kind, but there are also some chemical ones.

The oxygen potential required to burn fuel efficiently will also burn iron very efficiently, and the only reason why scrap melted in the Siemens furnace is not over-oxidized is that it is soon covered with slag; it is saved by the very feature of the Siemens furnace which the author condemns on grounds of heat transfer. Why do we not see efficient gas-fired cupolas instead of relatively inefficient ones using coke with a high loss of combustible gas at the top? The reason is that with a gas-fired cupola the steel would be hopelessly over-oxidized, and that might also happen in the shaft suggested by the author. If there is over-oxidized steel at the bottom and the molten pig iron is poured in through that, difficulties will be encountered with violent 'boils.'

Is the author satisfied that there will not be sulphur pick-up? He says that one of the advantages of his proposal is that "because the gases are fully burnt long before they come in contact with any metal . . . sulphur pick-up can be almost completely eliminated," but sulphur pick-up is quite serious even from completely burnt fuel if there is exposed iron and iron oxide, so that I do not think that his furnace would necessarily show an improvement there. It may be better than the Siemens furnace, but it will not overcome the problem. A recent paper* shows that sulphur dioxide as well as hydrogen sulphide will cause pick-up.

Engineers will be able to think of other difficulties, but I do not want to give the impression that I think that the proposed counterflow furnace has no advantages. It has, I believe, a tremendous number, but I suggest that the author has overlooked a few of the snags, or at any rate has not dealt with them in the paper. I must emphasize these because of the standing of the *Journal* and the number of people who read it; otherwise the industry might be severely criticized for not having gone ahead with some of these suggestions before. The only way to see whether these snags are serious is to build a prototype furnace. Dr. Chesters's recent address to the West of Scotland Iron and Steel Institute shows that Professor Thring has a supporter for his view that the industry must find a means of financing pilot-plant experiments of this sort.

I do not propose to refer to the other alternatives which the author mentions. The chief disadvantage of the recuperator plus waste-heat boiler system is not so much the theoretical thermal disadvantages caused by the limited preheat as that the heat-exchange surfaces will become hopelessly covered up with slag and dust and the heat-transfer efficiency will go down quickly.

I am sorry that the author did not say more about atomic energy in connection with the future of steel melting. What is his opinion and has he any information on the subject? So far as I can see, its only application will be through the generation of electricity for use in electric furnaces because the temperature required in steel melting or even in a reheating unit would be much greater than any of the known materials suitable for use in a reactor would stand.

These remarks may sound critical and a discouragement to forward thinking, but I do not underestimate the value of this paper. My remarks are made in the hope that the author will give further thought to some of these points and consider whether he still holds the view that the Siemens furnace is as defective as he has suggested when so many new ones are still being built in this country. I am sure, however, that a better furnace for steelmaking can be made, and the author will be one of the people who will help to build it for us.

Dr. **J. H. Chesters** (United Steel Companies Ltd.): I suggest that if the author's idea is tried out—and I have good reason to think that it will be—then, whether it succeeds or not, we shall obtain the answers to a number of important questions, and in particular the heat-transfer coefficient between waste gases and scrap. A great deal has been talked about this subject and about the allied problems of sticking and sulphur pick-up, and I feel the time has come to get new information rather than go on talking.

I agree with Dr. Leckie that Professor Thring's estimate of open-hearth efficiency is pessimistic, in that no allowance has been made for waste-heat credits. I feel as strongly as anyone else that a furnace should be designed to melt steel rather than make steam, but any incidental benefits from waste heat must be included in the overall balance. I think it should also be stressed that we are by no means at the end of the road in the development of the conventional open-hearth furnace. I have from time to time stressed the potentialities of intense combustion, and I would like to state quite definitely now that during the last few years we have made very substantial savings in oil by increasing the amount burnt in a given furnace. I believe that some day someone may achieve a fuel figure of 20 gal./ton for, say, an 80-ton cold-charged furnace with a relatively high metallurgical load. It will be far from easy and we may well have to wait 10 or 20 years to see it, but if it is ever achieved the margin between that set by

*P. T. Carter and S. Tahir, *J. West Scot. Iron Steel Inst.*, 1951–52, vol. 9, pp. 133–169.

the author and conventional practice will, of course, be substantially less.

Although the author has laid himself wide open to criticism in writing this paper, he has nevertheless done a service which I hope he may repeat, in that one of our biggest dangers lies in continuing a conventional line of development, even though it is not getting us anywhere very fast.

Dr. **T. P. Colclough,** C.B.E. (British Iron and Steel Federtation): We are all fully conscious that the O.H. furnace is not an efficient instrument. The preferable way of approaching this problem would be to make a critical examination of the reason for this and to see what steps can be taken to overcome the difficulties. The present paper does not go quite in that direction.

In 1922 a paper* read before this Institute gave probably the first heat balance on an O.H. furnace; I had a little to do with the preparation of that paper. The efficiency which was derived was 17%. Some progress has been made, because furnaces are operating today where that efficiency has been at least doubled.

Following that work on the practical side of making a heat balance, it was realized that the furnace was very inefficient, and an attempt was made to remedy it. Someone would suggest, " If we do so-and-so, that has an efficiency of 90%. We can then tack on to that so-and-so, which has a proved efficiency of 80%, add something else, also with a proved efficiency of 80%, and then something else which has a figure of almost 100%, and the overall answer will be 70%." That is more or less what happens in the author's Table II; but one of the greatest mistakes in the technical world is to string together things which are perfect in themselves but which when joined together are hopelessly wrong.

Let us examine one or two of the details. First of all, the author has made far too simple an analysis of this problem. A steelmaking furnace has other work to do besides melting scrap; it has to make steel. The furnace which is proposed has a hearth area of 1000 sq. ft. for 60 tons—*i.e.*, 16 sq. ft. per ton of metal. Steel cannot be made without having a slag on it, but how much slag must there be ? It must have heat to form it and keep it molten, but there are no allowances made for that heat requirement. We used to have the practical rule that to make good steel in a basic furnace there must be a minimum of about 3 in. of slag to prevent the metal being burnt. The author, in his opening remarks, directed appropriate attention to the fact that the thickness of the slag layer is an important factor in the transfer of heat. A 3-in. slag layer in this furnace means 35%, or about 20 tons of slag on the metal. What is the heat required for this slag ?

The author has not been as careful in his calculations as he might have been, because the next step is that the waste heat going out of the furnace shall be used to melt scrap in a cupola. The paper says that the cupola or chamber for melting this scrap will be 10 ft. in diameter and 8·6 ft. high. The author has assumed that the scrap will occupy half of the volume of that chimney; a factor of 2 must be taken into account there—$4 \cdot 5 \times 2$. Scrap never enters a furnace with a density of 240 lb./cu. ft. A scrap density of 70–80 lb./cu. ft. is a good one, so that this structure is nothing like so big as it ought to be at 8·6 ft.

The next point concerns the heat transfer in the chamber. The waste gases going through that chamber would have a time of passage of less than 1 sec., because the velocity is 72 ft./sec. and the height is 8·6 ft. The time of passage of the gas through the chimney and its contact with the scrap would be $\frac{1}{8}$ sec. How can 90% efficiency of heat transfer be visualized under those conditions ?

Has the author given any consideration to the building of this chimney ? Experience of melting scrap in cupolas suggests that the longest time one would stand up to the job was about 8 hr. in a reducing atmosphere. What would happen in this case, with the scrap being melted in an oxidizing atmosphere and with the formation of ferrous oxide and silicates which would be running down the walls ?

A recent paper by Cashmore,* which might with advantage have been associated with this one, emphasizes the importance of preheat. Professor Thring states that the air can be preheated in a metal recuperator with an efficiency of 80% to a temperature of 750° C. Nobody has been able to do this yet, and very important developments in another direction are awaiting proof that that is possible. A preheat of 750° C. is known to be undesirable in an O.H. furnace.

The O.H. furnace must be improved in efficiency, and one way to do so is to make it as nearly air-tight as possible. In the paper by Clements it is indicated that the way to improve the efficiency is to get better regeneration of the air. The O.H. furnace is said to be inefficient because, to maintain the speed of operation, water cooling must be used, and the amount of heat which goes away in water cooling is in some cases greater than the amount given in the paper as the total amount required in the furnace body itself. I suggest, however, that the regenerator chambers are efficient to a not unreasonable degree. Brick regenerators can be and are built with an efficiency of 90%. The reason why an efficient O.H. furnace is not obtained is that the regenerator system is not built correctly. If more heat is to be extracted from the waste gases (which is the way to improve efficiency) the metal recuperators must be put at the end of the present regenerators.

This is not a new idea; it was, I think, first introduced at Corby, where metal recuperators were put on the end of the regenerator chambers of soaking pits, to make them operate on blast-furnace gas.

Dr. **J. Pearson** (British Iron and Steel Research Association): I should like to warn the author of some of the metallurgical disadvantages which his proposed furnace is likely to possess.

He says that in his furnace " the steel flows through the refining chamber in 2 hr. since the thinner slag and shallower bath possible with a continuous system will considerably accelerate the refining reactions." This *may* be true, but what evidence is there for it ? Even with conventional baths, most refining reactions proceed fast, with the possible exception of carbon removal. Is there any evidence that carbon removal from a moving shallow bath *will* be appreciably faster than in the present O.H. furnaces ? This needs to be verified. The kinetics of refining reactions is a subject that still needs much investigation and it is therefore surprising to encounter a dogmatic statement like that quoted.

It is also stated that " metallurgical conditions should be very much improved over those in the present O.H. furnace because the gases are fully burnt before they come in contact with any metal, so that even with high-sulphur fuels sulphur pick-up can be almost completely eliminated."

This statement appears to imply a state of knowledge about the mechanism of sulphur pick-up which the physical chemist would be only too pleased to possess. Unfortunately, he has not that knowledge. In fact, on

*F. Clements, *J. Iron Steel Inst.*, 1922, No. I, p. 429.

*W. P. Cashmore, *J. Iron Steel Inst.*, 1954, vol. 178, pp. 112–121.

resent ideas, one would think that the proposed furnace would be practically objectionable where sulphur pick-up is concerned. In the scrap-heating column, steel without a slag cover is subjected to the action of gases containing not only excess oxygen but also sulphur dioxide. It is hard to conceive that there will be no sulphur pick-up under these conditions. Thermodynamic calculations indicate that unless the partial pressure of SO_3 in the waste gases is very low indeed, heavy sulphur pick-up is to be expected.

It should also be noted that the waste gases containing SO_2, O_2, and H_2O are cooled in the scrap column (which will contain rusty scrap or surfaces oxidized by the gases themselves) down to 170° C. In this range, and particularly at about 400° C., combination of SO_2 and O_2 to give SO_3, catalysed by the iron oxide, is to be expected. Below about 350° C. condensation of H_2SO_4 will occur. This 'band' of H_2SO_4 will remain stationary in the column, but some will react to produce $FeSO_4$, which will descend with the scrap and be decomposed at temperatures of 600–800° C. and some sulphur pick-up can result from this. Is this scrap column not, in fact, a device for removing sulphur from the waste gases?

There is another feature of the proposed furnace which also appears to be objectionable in regard to sulphur pick-up. It is known that the conditions which favour the movement of sulphur from gas to metal via slag are those present when fuel is only partly burned. The position at which uncombusted gases are present in the new design is that at which the steel leaves, so that if any pick-up does occur there is no time for it to be removed, under oxidizing conditions, before the steel is tapped.

The suggested design has a slag bridge, "so that the first slag can be skimmed off and a second one built up for the final refining to give a very high quality steel." Presumably the ingredients for the first slag will be added with the scrap and it is therefore essential that the rate at which they melt and form slag be constant and uniform. This might be very difficult in practice.

The slag ingredients necessary to deal with a mixed scrap–hot-metal charge will of course be different from those for an all-scrap charge and their rate of arrival at the metal entrance end of the furnace will have to be nicely correlated with the hot-metal additions, for it is hard to envisage the latter being made continuously, uniformly, and uninterruptedly. Very careful control would have to be exercised to ensure that the slag being produced was correct for the metal in the first part of the furnace and not, for instance, too oxidizing for a high-scrap melt or not sufficiently oxidizing for a high-hot-metal melt.

The first slag is to be skimmed off continuously. This means that it must have done all the metallurgical work intended—no more and no less. The chances are that it may run off at the slag notch either so highly oxidized that it would substantially lower the metal yield or so reduced that it would not have adequately removed the impurities. Other possibilities will occur to the reader. To sum up, it must be possible for the furnace to be run in such a way that the first slag can be produced of such a composition and at such a rate that it will always leave the furnace with the correct composition after having done the correct amount of refining. If it does not, the second slag cannot be correctly formulated.

The same considerations apply to the second slag as to the first. Once the ingredients are added, nothing further can be done: the slag will pass along the furnace on top of the flowing steel and must always be capable of dealing with a chance variation in composition of steel or of reaction rates.

It is possible that these thoughts about slags are wrong. If the two chambers of the furnace are regarded as reservoirs into and out of which flows steady 'trickles' of metal and slag and in which metal and slag are effectively, though separately, mixed, then in each chamber the composition of metal and slag will not change appreciably with time. The final slag will then have to be of 'tapping' composition, since it will be above a metal which is essentially ready for tapping. Control of slag and metal will then not be so difficult, for periodic samples would show any tendency to change in composition and the slag additions could be altered appropriately.

To what extent such mixing is possible with a bath 4 in. deep moving forward at an overall rate of 6 in./min. is not known. It should be noted that the proposed output of 30 tons/hr. represents half the contents of the refining chamber at any time, i.e. steel is entering and leaving the furnace at such a rate that if there were no mixing the contents would be changed completely every 2 hr.

Dr. **C. A. Edwards,** F.R.S. (Swansea): I agree with what has been said about sulphur pick-up. I think that the author's proposal is going to lead to very much more sulphur pick-up than at present in the ordinary O.H. furnace, because the whole of the scrap is being exposed during the whole of the melting period to these waste gases, whereas in the ordinary basic O.H. as at present used much of the scrap is well below the slag level as soon as hot metal is put into the furnace.

It is doubtful whether the author will get any metal at all at the bottom of his column, because the extent of the oxidation will be so great that most of the scrap will be converted to oxide of iron. This will give rise to excessive corrosive attack on the furnace hearth. Even if there is some metal at the bottom, the excessive amount of oxide of iron obtained will cause such vigorous reactions at that end of the furnace that the furnace life will be very short.

I believe, however, that it might be possible to minimize the sulphur pick-up which is so serious in O.H. practice by having a unidirectional flow; in those conditions it would be possible to ascertain just where the maximum degree of sulphur pick-up occurs, and if it is at the outgoing end of the ordinary furnace perhaps the bulk of the scrap could be placed in that position, thereby decreasing the rather heavy degree of sulphur pick-up which is now obtained when using high-sulphur fuel.

Can the author assure us that there is a simple method of getting rid of the slag as easily as he suggests is possible in glass-making operations? Perhaps he can give us some idea of how to get rid of this slag at any particular stage in the O.H. process, because so far as I know there is no practical method of doing this.

AUTHOR'S REPLY

Professor **Thring:** The suggestions made (putting recuperators after regenerators, making the furnace tight, eliminating water-cooling, and the use of intense combustion) for improving the open-hearth furnace are good, and I am delighted that my paper about an alternative is producing defenders of the open-hearth furnace who are suggesting ways in which it can be improved. The paper will have been useful if it has persuaded people to do these things on the open-hearth furnace.

I do not agree with Dr. Colclough that I have assumed that the column is 90% efficient. I have assumed that 10% of the heat is lost in the walls, but I have also assumed that 10% is left in the gases going out, so that it is only 80% efficient. If that is reduced to 70% the fuel figure is still very good.

I have done further calculations on this type of process for producer-gas firing, and even there I get a very satisfactory figure, the equivalent of about 12 gal./ton of oil with producer-gas firing, after dropping the efficiency of the air heater to 70%, which should satisfy Dr. Colclough better. The proposed process offers considerable benefits, so that even allowing for most of the criticisms which have been made, I still think that it will be better than the present open-hearth process. Dropping the efficiency of the air heater to 60% only lowers the overall efficiency by a few per cent.

I agree that the problem of the brick lining of the chimney is a considerable one, but it is not insoluble. An answer can be found and the heating column can be made tight very easily. I agree with Mr. Mitchell's doubts about the sloping ramp method of charging, but with this column it will be possible to produce a marked improvement in the fuel consumption.

There are one or two points which are not quite clear. In these calculations I have assumed that the latent heat of fusion is provided in the bath and not the column. The cast leaves the bath at 1600° C., but the metal comes down into the bath solid at 1500° C. It would improve the thermal balance to take the latent heat in the column, but I have deliberately not done so, in order to load the dice a little against the proposal.

Questions of scrap density are not serious criticisms, because if it is half what I have taken a column twice as high would be used without difficulty. The height of the column to get the degree of heat transfer is a problem. Working out the heat-transfer coefficients in the column gives a height of column much greater than 8·6 ft., which was calculated on the basis of emptying the whole furnace in 4½ hr. From the point of view of heat transfer I agree that a much higher column would be needed, considerably higher than 8·6 ft.

The thickness of the slag on the furnace is very much on the lap of the gods. I deliberately assumed a very thin slag and a very thin bath, because I think that the real problem with steelmaking is to get contact between the slag and the steel. If they are both thin the molecules do not have to move so far to reach the surface of contact, which is an advantage. Assuming a thicker slag and a thicker bath of metal gives a very much smaller chamber at the end, which greatly improves the cycle. The bath area can easily be reduced, therefore, which produces an improvement in the thermodynamics.

I agree with Dr. Leckie in not seeing any way of using atomic energy for steel melting except *via* electricity. I used to like to think of an 'apple dumpling'—a refractory wall containing an atomic reactor which would produce heat at the high-grade temperature needed in a steel furnace—but radioactive contamination of the charge is an insuperable difficulty. We must therefore allow those concerned with atomic energy to degrade their energy to steam and turn that into electricity for our use.

To some extent Dr. Pearson's two criticisms about sulphur are self-contradictory, because on the one hand he blames me for having unburnt gases, producing a great deal of pick-up, and yet on the other he says that even when the gases are fully burnt in the column there will still be a great deal of pick-up.

Metallurgical criticisms have been made of the processes in the column, particularly that the scrap will oxidize away entirely and will reach the bottom of the column entirely as iron oxide. Here the perfect answer is that given by Dr. Chesters—try it and see. We cannot guarantee that that is what will happen, because, if it did, why does not the flame in the present open-hearth oxidize all the scrap which is piled up before melting it ?

Another criticism of the working of the column is that the convection heat-transfer coefficient is not known exactly. The only way to answer that would be to find out; the indications are that the size of the column would not be unreasonable from that point of view. If these difficulties about oxidation and sulphur pick-up are not excessive, I still think that incoming scrap and pig iron are the best materials on which to use the low-grade heat from the process, and that is why I think it is a proper step forward. The same answer applies to the criticism that the refractories will not stand up; I do not think that the refractory makers would admit that that was an impossible problem.

It has been said that it would be impossible to fettle the bath. There is always a tendency to think in terms of the process which has been operated for the last hundred years. With a semi-continuous or continuous process the fettling problem would be quite different from the present one. At present the bottom of the bath has to stand all the different stages in the melting process and therefore has to be a compromise between the ideal materials for all these stages. With a semi-continuous or continuous process the material would be right for each stage at the right place ; it would last longer than it does at present, so that it would only be necessary to patch up the bottom occasionally, say once a week when the furnace was emptied. The problem of the mechanism of introducing the fettling material could be solved without the doors at present supplied to the open-hearth furnace.

It is true that I have not allowed in the calculations for the heat to melt the slag materials, nor for the heat released by oxidation of materials of the charge, two factors which will largely cancel one another out. The criticism is also made that skimming the intermediate slags would not work in the same way as in tapping off liquid glass, but certainly some solution must be found to the problem caused by thermal resistance of the slag in the open-hearth.

I can summarize the position by saying that the metallurgists do not know enough about it at the moment to say that this process would be impossible, and therefore the best answer would be to try it and see. Even if it failed we should have learnt a great deal more about the metallurgy, which would be useful in improving the open-hearth furnace. The fact that the testing of a new process such as this would give, if nothing else, at least reasons for improving the open-hearth furnace is a useful point, and another is the spirited defence of the open-hearth furnace, which has been coupled with suggestions whereby the open-hearth furnace can be improved, suggestions which, if rivals come along, will obviously be applied.

CORRESPONDENCE

Mr. **D. J. O. Brandt** (B.I.S.R.A.) wrote: I have known Prof. Thring for seven years and during that time have conceived a great respect for his ability as a physicist and a mathematician. In one respect, however, I cannot help feeling that he suffers from some kind of obsession or delusion, namely, that he appears convinced that open-hearth baths are flat and motionless, and therefore the heat transfer from the top to the bottom is a straightforward process of readily calculable heat flow.

I submit that this is not the case. Right from the start of melting the open-hearth bath is reacting vigorously, the mechanism of heat transfer is a much more complex affair, and therefore Prof. Thring's ideal of an ultra-shallow bath is wholly unnecessary. Open-hearth

steelmaking is a chemical process as well as a physical one and the chemistry of the operation not only governs the removal of the metalloids, but also has a profound effect upon the thermal balance and heat transfer.

The importance of constant bath activity is well known to any melter. In the final stages, as long as he maintains the boil he can be reasonably sure of bringing the temperature up and keeping it up, but if he overfeeds the bath and allows the boil to die away, he will experience great difficulty in bringing the temperature up again without damaging the roof. Heat transfer in the open-hearth cannot be regarded as flowing through a series of static layers—atmosphere, slag, and metal—and calculations based upon this premise are therefore suspect from the start.

Apart from this, I would like to venture a prediction. If experiments do indeed proceed on Prof. Thring's continuous counterflow furnace, one of two things will happen. To overcome the difficulties which will be experienced with the column of cold incoming scrap this will either have to be progressively whittled away until it disappears altogether, or coke will have to be added to it to increase porosity and check oxidation. In the first case, therefore, the experimenters will be virtually back where the German trials were in 1939; in the second case they will be very close to melting the scrap in a cupola. If the latter expedient is resorted to, the investigators would be well advised to scrap the rest of the furnace and convert their cupola-melted metal in a simple ladle with an oxygen lance. This is not a new departure; its feasibility has been proved* and it is coming into everyday use. Moreover, it has not required the expenditure of £5000.

* D. J. O. Brandt and W. S. Williams, *Iron Coal Trades Rev.*, 1954, vol. 169, pp. 516–518.

AUTHOR'S WRITTEN REPLY

Professor **Thring** wrote in reply: In reply to Mr. Brandt's first point, the work which I and my colleagues have been carrying out for some years on developing an adequate theory of heat transfer in the open-hearth furnace has now reached a stage at which we can obtain good agreement between the heat-transfer rate predicted from the flame input variables and the melting time and roof temperatures which actually occur. As a result, we have a quantitative measure of the resistance to heat transfer between the surface of the slag and the bottom of the bath. This confirms Mr. Brandt's comments, since it works out at the equivalent of about 1 in. of solid steel, which is much less than one would expect at first sight from the thermal resistance of a slag-like material several inches thick. However, the fact that we have the quantitative measure of the true thermal resistance shows that it is not neglected. It is well known that an increase in the slag bulk necessary for metallurgical reasons slows down the melting rate very considerably, and it is for this reason that we have recommended the reduction in thickness of the bath in a continuous process. Nevertheless, reduction of the thickness of the bath is not the centre of gravity of the suggestion I am putting forward, which is the use of the lower-grade heat in the hot gases from the final refining chamber to melt the incoming cold material in a counterflow heat exchanger.

My answer to Mr. Brandt's second point is that we may well need some coke in the shaft, but that nevertheless I consider the combination of a shaft with a flame-heated refining chamber a very desirable step forward.

DISCUSSION ON BILLET RUPTURE IN CONTINUOUS CASTING

This discussion was based on the paper by J. Savage and W. H. Pritchard entitled **"The Problem of Rupture of the Billet in the Continuous Casting of Steel,"** which was published in the November, 1954, issue of the *Journal* (vol. 178, pp. 269–277).

Mr. **J. Savage** (B.I.S.R.A.) presented the paper.

Mr. **G. T. Harris** (Wm. Jessop and Sons Ltd.): The authors are to be congratulated on presenting very clearly some of the fundamental principles which lie behind the use of the B.I.S.R.A. continuous-casting mould and the alternative moulds which have been tried. The paper puts on a firm scientific basis a good deal of what has already been published in the patent literature and elsewhere without any very adequate explanation of the reasons behind the success or otherwise of these moulds. The authors' approach is interesting because it indicates how two particular systems, the Junghans mould and the B.I.S.R.A. mould, have been applied to a practical commercial form of continuous casting.

The pilot plant to which the B.I.S.R.A. mould has now been applied is in some sense a private venture. It is a plant based on the B.I.S.R.A. ideas but financed by a group of 11 interested steel companies who wanted to know how this system could be applied to high-speed and special steels. This group, which has financed the erection of this plant and its running by Jessops, is at the moment a little reticent about disclosing too much of the operating experience, preferring to wait until a reasonable measure of success has been attained and the co-operating members can have the opportunity themselves of putting down plants. For this reason I cannot enlarge very greatly on the practical fulfilment of the system outlined by the authors, but I think it is fair to say that in the six months for which we have been operating at Jessops we have had no undue difficulty through failure of the process due to the frictional problem which is discussed in this paper. Thus, the solution of the friction problem which has been provided by the B.I.S.R.A. mould has worked out satisfactorily in practice.

The comparison of the operational methods of the Junghans and B.I.S.R.A. moulds is interesting, especially the suggestion that the Junghans type gives an irregular solidification front due to the repeated breaking and healing which may take place. This may be linked with sporadic centre-line shrinkage and porosity problems with the Junghans type of mould, and it may be that the B.I.S.R.A. process, which overcomes the friction and prevents skin rupture (rather than healing it after it has been formed, on the Junghans principle) may have distinct advantages, particularly for high-alloy steels where centre-line shrinkage can be much more important than with mild steel.

The figures quoted for the Junghans mould for rate of casting are much higher than are referred to in this paper as being typical of the B.I.S.R.A. mould, being up to about 20 ft./min. For special and high-alloy steel

however, there may be other reasons why a high rate of casting is not desirable. It may in fact be better to cast high-alloy and high-speed steels much slower than is apparently common with the Junghans plant.

In this case the logical development has to be that to get large tonnage outputs it is necessary to resort to multi-strand casting. The Jessop plant is a two-strand design and was designed as such when it first went in. It is fair to say that the joint work of B.I.S.R.A., the plant manufacturers, and ourselves has resulted in a satisfactory solution to the two-strand operation of continuous-casting machines, but we have to look to the future, when many more strands may be necessary, and this development will introduce difficulties related to the control of multiple streams.

I would point out also, as Mr. Savage has done in presenting the paper, that the mould is only one of the many problems associated with the commercial application of continuous casting. It is necessary to make the steel and tap it, as a rule, at a temperature in excess of that which has been considered desirable in the best steelmaking practice. It must then be maintained at an excess temperature in the ladle, and to do this, suitable refractories and ladle bricking arrangements must be used. A slag may be maintained on the metal to minimize the radiation losses, but this involves special techniques to ensure that no slag goes through the pouring system into the continuous-casting mould.

Below the mould we have to abstract heat from the billet surface as rapidly as possible, and this may involve some form of water quenching, but in such a way that the billet is not cracked; this is often difficult with high-speed and other special steels.

It is then necessary to take the billet off at the bottom end. This seems fairly simple but, as has been pointed out, flame-cutting or saw-cutting high-alloy steels in a very short space of time (of the order of 20 sec.) introduces problems, including those of leaving the material undamaged.

I should like to emphasize the importance of Fig. 16 in this paper. It is a delightfully simple explanation, showing that if two lines do not intersect the billet does not rupture; but one of these two lines is a curve derived from several quantities, none of which is properly known. It involves first the thickening of the solid skin with time, and this depends on the latent heat of the steel and the thermal constants of the steel at temperatures near the melting point. It is hardly necessary to point out that these quantities are not well established for pure iron or mild steel, and certainly they are only estimates for high-alloy steels. The second major factor relates to the strength of this steel at temperatures between (say) 1200° C. and the melting point. A good deal is known of the hot strength of steels at temperatures up to 1000° C., very little of the strength of ordinary steels at temperatures between 1000° C. and the melting point, and still less about complex steels at these temperatures.

This information on the thermal constants and hot strength of various steels at temperatures between 1000° C. and the melting point would be useful not only in the problem of rupture in continuous casting, but in that of rupture in the cooling of conventional ingots (longitudinal panel cracking) and the hot tearing of castings. It would be a very useful extension of the work of B.I.S.R.A., as part of the next stage of their programme, if the constants required for determining the rate of thickening of a steel skin at temperatures between 1000° C. and the melting point could be determined, and data collected on the strength of solid steels at these temperatures.

Mr. D. M. Lewis (Aluminium Laboratories Limited): In the early stages of the work described it was my privilege to assist to some extent, and it was thus a great pleasure to read the first published account of the results obtained in the B.I.S.R.A. continuous-casting work. My interest in continuous casting has now moved to light alloys, but I feel that results obtained in our present work may help to clear up some of the problems being met by the B.I.S.R.A. team.

The explanation given by the authors for the rupture of the metal skin seems to be feasible, but it deals with only part of the problem. In their Fig. 1 the initial rupture is shown as taking place at the point X, but why does this happen at X? That is a position where the skin is relatively thick and, as the authors imply later in the paper, fairly strong. They go on to suggest that the ingot-mould friction is responsible for the stresses resulting in rupture. Whilst accepting this, I would suggest that another mechanism comes into play and it is this which results in the first actual break.

The evidence for my suggestion is frequently obtained in the continuous casting of light alloys. We consider that solidification starts at the point shown by the arrow in Fig. A (i) and proceeds uniformly for a short time as the metal moves downward. As freezing proceeds the solid ring shrinks and an air gap is formed, this, in some cases, effectively ending further deposition of solid. Heat transfer from the billet to the mould wall is now drastically reduced, but thermal conduction can still take place from the liquid core into the cooler solid skin, resulting in the whole skin rising in temperature. The temperature of the outside layers can rise above the solidus with the result that the low-melting-point constituents tend to ooze through this surface, being responsible for the well-known blebbing effect.

I would suggest that in the casting of steel this reheating does in fact occur, and that a certain amount of remelting of the skin can take place. Thus it is possible that with some steels the temperature of the skin as shown in Fig. A (ii) actually exceeds the solidus. There is then a condition where a pull is being applied to the billet by the withdrawal mechanism, the initial skin is subject to friction forces on the mould, and in between there is a portion of metal having negligible strength. This weak link ruptures and then the process probably follows the sequence described in the paper. The reheating and remelting of the billet skin has been the subject of much work by Siebel and Altenpohl.[1, 2]

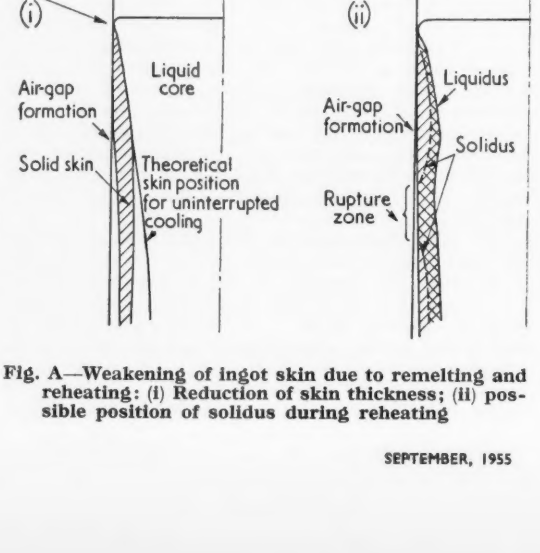


Fig. A—Weakening of ingot skin due to remelting and reheating: (i) Reduction of skin thickness; (ii) possible position of solidus during reheating

It is unfortunate that the authors of the present paper have not included any metallographic evidence for the tearing theory they propose. It will probably not be too difficult to obtain etched sections showing stages in the rupture process.

Figure 2 attempts to relate the rupture process to changes in mould heat transfer, but this diagram shows the integrated values of heat transfer, not the individual values. Can the authors say what the effects are when much smaller zones of the mould are considered ?

The work done on lubrication is most interesting and certainly provides overwhelming evidence for efficient mould treatment. The authors favour the use of oils, but have they examined the effect of very thick greases applied to the mould face before the casting starts ? It might also be useful to examine the effect of having a very thin layer of molybdenum disulphide grease on the mould wall. This lubricant might not require frequent renewal.

Turning to the discussion of heat transfer and freezing rate, I feel it would be more useful if equation 4 on p. 275 were rewritten to give straightforward values of x, the skin thickness, as it would then become clear how x varies with the other quantities, skin thickness being the most interesting variable in the investigation. It appears that the change in rate of skin thickening, i.e. probable air-gap formation, occurs at about 3 sec. Have the authors been able to check whether this takes place at the same time at all casting speeds ?

Up to now the authors have relied on a variant of the pour-out method for getting a knowledge of solidification contours. This is somewhat unfortunate as it is now generally accepted that the pour-out technique is misleading and unreliable. More useful results could probably be obtained by using some of the recently described tracer techniques.[3, 4]

I would like to emphasize the very great importance of metallographic examination of the casting process at the same time as purely physical study. Taken on its own, the latter can be misleading. The exact composition and characteristics of the metal being cast must be known and considered for there are vast differences in casting behaviour between relatively pure metals and alloys consisting of solid solutions and eutectics. It seems that the success or failure of continuous casting depends on what is done to the metal around its freezing point. Direct observation is thus not possible, but much can be deduced from study of the metallographic features present in the cold cast products or in the broken pieces resulting from those casts that failed.

Dr. **V. Kondic** (Birmingham University): Before I raise a few general points concerning this paper, I should like to draw a contrast between continuously casting non-ferrous metals on the one hand, and steel on the other. The outstanding metallurgical difference is a considerably higher pouring temperature of ferrous metals, and thus a larger temperature drop in the mould, as compared with non-ferrous metals. Owing to lower temperatures and temperature gradients a much greater degree of freedom exists in choosing the cooling method in continuously casting non-ferrous metals than for steel.

On the production side the chief contrast is in the sizes of ingots and the tonnage of metal normally required to be cast. The non-ferrous field is characterized by relatively lower melting rates and smaller ingot sizes. Steel producers, on the other hand, generally handle larger quantities of molten metals and frequently cast ingots in large sizes. The extent of future development of continuously casting mild and low-carbon steel very likely depends on a successful solution of these production problems.

Turning now to rupture of continuously cast steel ingots, the first point is that this problem is a very old friend of all non-ferrous users of the continuous-casting process. There are two major general conclusions obtained from the non-ferrous field. Firstly, alloys that are most prone to this type of defect during casting are those having a large solidification interval. In this connection I should like to comment on the way in which the authors drew the solid zones of solidification of ingots in their paper, as well as on Mr. Lewis's sketch (Fig. *A*). In by far the largest number of cases of casting, the all-solid zone is separated from the all-liquid zone by a pasty zone whose depth is one of the major problems encountered in the metallurgy of casting in general and continuous casting in particular. It is this pasty zone that is largely responsible for the origin of rupture during casting as shown by the fact that pure metals and eutectics are cast relatively easily by the continuous process.

The second general point relating to the problem of rupture of continuously cast non-ferrous metals is the method which is normally used to overcome this difficulty. Owing to the relatively lower temperatures involved, as I have already indicated, the length of the pasty zone is reduced to a very short length by using a very short mould. A 3–4-in. deep mould is sufficient for casting even the largest sizes of most non-ferrous ingots. What is important, however, is that in this case the friction between the ingot and the mould is very much reduced and thus the stress causing the rupture is made very much smaller.

We can now turn to the problem of rupture as discussed in the paper and in relation to the general points which I have just made. Clearly the solution of this problem can be considered along two different lines: firstly, that of increasing the strength of the ingot skin which is subject to the stress whilst it is in its weakest state and, secondly, that of reducing the stress causing the rupture. The former solution is that which is normally applied in continuously casting non-ferrous metals. By shortening the mould and using a very drastic quench below the mould the ingot skin is made sufficiently strong to resist the friction pull. Unfortunately this solution leads to another difficulty, that of the generation of quenching stresses. Thus the correct solution has to be a compromise, the optimum cooling rate and cooling method being normally found by experiment. Because of the high temperatures encountered in continuously casting steel, the short-mould solution does not appear readily applicable in this field. The second solution, that of minimizing the stress between the mould and the ingot, makes use of some of these ideas: mould lubrication, oscillation, vibration, or rotation. The solution proposed by the authors makes use of both of the above principles; the skin thickness is built up during the non-slip stage of casting and the mould is lubricated to reduce the friction. Yet another solution appears feasible, namely that of making use of a mould which has two cooling zones; one in which the metal is maintained molten and the other in which the rate of cooling is made very intense. I have been successful in overcoming the problem of rupture in continuously casting some non-ferrous alloys by making use of this principle, but would not like to suggest that the same would hold with equal ease for steel. The idea, however, appears to me to be worth trying out.

Finally, I would like to suggest to the authors to adopt in future the term ' hot tearing ' instead of ' rupture ' to describe the problem under discussion. I have used ' rupture ' myself for continuity but ' hot tearing ' is preferable because, firstly, it describes accurately the nature of the problem and, secondly, the

same term is generally used in both ferrous and non-ferrous casting metallurgy.

Dr. **B. H. C. Waters** (Wm. Jessop and Sons Ltd.): There are a few comments on this excellent paper which I should like to make.

On p. 273 there is mention of a liquid boundary layer of lubricant which may be expected to exist at the inner mould-face. I agree that in the continuous casting of steel a liquid layer of lubricant does persist at the mould-face, going down below the level of the metal in the mould, but I do not think that conventional boundary lubrication occurs. I would have expected the lubrication to be of the fluid type, the fluid arising from the vaporization of the oils that are used, so that it seems unlikely that with steel there is, in a lubricated mould, any very considerable zone in which the metal is in intimate contact with the mould. Again, were the lubrication not of the gaseous fluid type, I should have expected the oils used to show some form of gumming polymerization, since they are operating below their volatilization point but at some temperature above 200° C., the inner temperature of the mould-face; for this reason they might well inhibit rather than help lubrication. The question of lubrication with a grease may be important, but in casting steel it is very difficult indeed to get a grease which will maintain sufficient viscosity to keep it in the mould for any length of time at the temperatures involved. Thus I feel that provision must be made for continuous lubrication.

The friction records shown in Fig. 7 of the paper are very interesting, although some would be surprising to anyone coming new to the subject of continuous casting. For brass the friction can be very low: this, I suppose, would be expected. It is a smooth surface, and even unlubricated there would be very little friction. With the chromium-plated mould the result is surprising. I imagine that at some stage there must be near jamming between the billet and the mould, corresponding to the high frictional peaks shown. Presumably, this jamming also brings about intimate contact between the ingot and the mould, causing a rapid loss of heat by the ingot at the point of contact with a consequent contraction, drawing away, and freeing of the ingot from its stuck position. It would be interesting to know how much wear took place on some of these highly polished brass moulds, and also whether the plating on the chromium-plated moulds was uniform or in any way rippled, so that the ripples might cause this kind of frictional effect. The authors refer to the extensive use of chromium-plated moulds in many of the pilot plants at present operating, and I should like to ask whether most continuous-casting plants still employ chromium-plated moulds, and also to ask how these moulds are lubricated when they are used.

I understand that in some of the Continental plants moulds are used which do not have springs, which do not have reciprocation, and where intermittent withdrawal is not employed. How do they work ? Do they work by means of a very efficient lubrication system and, if so, are they commercially workable propositions ? We have seen from the paper how frequently the friction can rise with these moulds. If we try to work a continuous-casting process on a commercial basis, we certainly cannot tolerate break-outs in more than, say, 1 in 100 casts. It would be a very serious matter if we could not be certain that the mould would work.

Dr. Kondic has pointed out that in the aluminium industry the mould length can be reduced very considerably. In the early days of considering the continuous casting of steel in this country there was much discussion, in a somewhat dilettante way, on the effect of lengthening and shortening the mould. In this paper one of the main items of discussion at that time—the friction in the mould—has now received considerable attention and several of the answers to difficulties which then presented themselves have been obtained. Could we now start thinking in terms not of a shorter mould but of a longer one ? Would the authors care to comment on the question of how long we could make the mould ? What is the optimum length ? If the fabrication difficulties could be overcome, might we be able to think in terms of a mould 10 ft. long instead of the 13 in. mentioned in this paper ?

AUTHOR'S REPLY

Mr. **J. Savage** (in reply): Several very interesting points have been made by all the speakers, and I would like to thank them for the helpful and valuable suggestions that have been put forward; it is not possible in the time available to attempt to answer fully all the questions that have been raised. I agree with Mr. Harris that the work which we have done so far has indicated a large gap in our knowledge of the thermal constants and the rupture strength of steel, particularly of special steels between 1200° C. and the melting point. Figure 16 in the paper refers to a 0·2% carbon steel which is a relatively straightforward one from this point of view. We are now working on the measurement of the thermal constants of some of the more complex steels which are of special interest. In reply to another point made by Mr. Harris, I do not wish to suggest that in the Junghans–Rossi process rupture of the billet occurs at each reversal of the mould, giving rise to an irregular solidification front as shown in Fig. 4. My view is that at high enough speeds the skin may occasionally be ruptured and healed as described in this paper, but it is even more probable that at speeds up to a few feet per minute and with good lubrication, rupture of the skin will not occur at all.

Mr. Lewis mentioned the probable formation of an air gap and a consequent reduction in the rate of solidification. This argument has been put forward very often in the literature on continuous casting, including patent specifications, but we have never found any evidence of the phenomenon by measurement with steel. We have never detected any abrupt break in the rate of heat transfer, which must be the case if an air gap is formed suddenly in the mould. This is not to say that it does not occur with aluminium, but I have not yet seen any experimental results to support this argument. He asks whether greases could be used in place of the lubrication systems which we have suggested. Dr. Waters answered that question as I would have done by pointing out that it is very difficult to maintain a grease as a lubricant in the case of steel for a long enough time, although I do know that it is possible with non-ferrous metals.

A very great deal of work is being done on the metallurgical examination of continuously cast steel, and we hope that a paper will be published in due course; however, it was never intended to form a part of the present paper. The tracer method, used by Mr. Lewis for investigating the solidification front in the continuous casting of aluminium where the liquid core may be a few inches deep, would be far more difficult to apply to steel where the liquid steel core may extend many feet under some conditions of casting.

Dr. Kondic mentioned casting processes using vibrating moulds. Whilst numerous patents have been filed on such systems, I do not know of any plants where vibrating moulds have been applied commercially. In this paper we have only referred to systems which have been found practical and are, in fact, being used. We have deliber-

ately avoided mentioning other casting systems which, to our knowledge, have not achieved any practical success for steel, including the first continuous casting process suggested by Sir Henry Bessemer.

I agree with Dr. Waters that it is unlikely that we ever have intimate contact between the billet and mould surfaces when lubricants are applied. It is probably unwise to draw too many specific conclusions from the friction records reproduced, even though they are taken from actual experimental records. They are, however, indicative of the general behaviour of the various mould surfaces on which experiments were made. Several plants adopted chromium-plated moulds, largely to reduce wear, and when used in conjunction with lubricants these were probably satisfactory. Without oil, our results indicated that chromium plating was inferior to a polished brass or copper mould. Dr. Waters has referred to Continental continuous-casting plants in which the mould was fixed and the billet withdrawn at a uniform speed. He asked why this system worked when so much emphasis was being made on the likelihood of rupture under such conditions. The answer to this had already been given on p. 273 of the paper in the reference to the plant operated by Bohler in Austria. Provided that the lubrication of the mould was satisfactory, the low friction forces made rupture unlikely. To counteract the consequences of failure or inadequacy of the lubrication, casting systems such as those described seemed to be essential. He has also raised the question of mould length, and asked why this should not be increased. The essential function of the mould was to produce the billet shape required and a strong enough skin to enable the cast steel to be passed into secondary cooling sprays and withdrawal rolls. Measurements had shown that continuous-casting moulds were not highly efficient in extracting heat from the steel. For this reason, as in the non-ferrous industry, it was better to keep the mould as short as possible, and to extract the bulk of the heat from the steel by water spraying outside the mould. Short moulds had two other advantages: they were easier to fabricate and to maintain in good condition, and also gave a lower frictional drag by virtue of their short length.

One point has not been raised in the discussion. The title of the paper referred to billets, but it should be emphasized that the as-cast product could not really be regarded as a billet in the accepted metallurgical sense. The term has been introduced by common usage, largely because the cross-sections of continuously cast steel were generally in the billet size range. On the other hand, the metallurgical as-cast condition of continuously cast steel lies somewhere between the quality of conventional ingots and billets. More will be said later about the metallurgical aspects of continuous casting.

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Correspondence on the Paper—

The Universal Decimal Classification Applied to Metallurgical Literature*

By EINAR ÖHMAN and J. P. SAVILLE

Mrs. **Marjorie R. Hyslop** (Managing Editor, *Metal Progress*, and Editor, *A.S.M. Review of Metal Literature*) wrote: Mr. Öhman and Mr. Saville have given an excellent introductory explanation of some of the intricacies of the Universal Decimal Classification (U.D.C.). A point which is not sufficiently emphasized, however, is that the Universal Decimal Classification is designed for use by the bibliographical specialist or trained librarian rather than the practising engineer or scientist. Few engineers or researchers, metallurgical or otherwise, have the time or the inclination to study even the relatively simple Dewey classification scheme intensively enough to adapt it to their own literature filing problems. The Universal Decimal Classification has the advantage over Dewey of providing a much more complete coverage of the field of metallurgy, but in incorporating these minutiæ into a scheme which covers the whole of knowledge in similar detail, an extremely complicated and cumbersome symbology is required.

It is for this reason that attempts are continually being made to devise a system for referencing metallurgical literature that will be compact, fairly simple, and usable by those whose training does not necessarily include a degree in library science. This at least was the original reasoning behind the formulation of the ASM/SLA Classification of Metallurgical Literature (devised jointly by the American Society for Metals and the Special Libraries Association); doubtless similar considerations prompted the development of the French Alpha-Numérique Classification.

An example of the U.D.C.'s complex notation system can be taken from Öhman and Saville's paper: the heat-treatment of stainless steel (a fairly broad subject in itself) is characterized by the notation 621. 785: 669. 14. 018. 8. In the ASM/SLA classification the idea would be conveyed by ' J General, SS.' Nickel–chromium alloy steel in U.D.C. language is 669. 15. 24. 26–194; in ASM/SLA it is simply AŸ–r. Do not these latter classifications appeal to one as speedier and more accurate, the same desiderata of any classification mentioned by the authors in their last paragraph ?

J. Iron Steel Inst., 1954, vol. 177, May, pp. 183–188.

A second and serious defect of the Universal Decimal Classification from the standpoint of metallurgy is the scattering of various parts of the subject throughout a number of principal headings. Öhman and Saville themselves point out that a metallurgical 'guide' to U.D.C. would require complete U.D.C. schedules on the mining, extraction, and working of metals, connected by abridged schedules on physics, chemistry, geology, electrical engineering, the social sciences, and others. The authors state that this defect arises not from any weakness in the system itself but from the quite recent and enormous expansion of meaning that the word metallurgy has received. This means that 'metallurgy' in U.D.C. retains its ancient and classical concept of extraction and refining of ores; section 669 on metallurgy is confined to this subject, plus a classification of such subjects as physical properties, mechanical properties, testing, heat-treatment, metallography, forging, foundry work, rolling, welding, machining. At first glance, this does not strike an observer as being simple.

It can be conceded, of course, that in a classification of all of knowledge, or even of all of science, certain subjects of great interest to the metallurgist are natural subdivisions of a larger science, and perforce fall victim to the cross-reference. Nevertheless, this is of no help to the metallurgical researcher or even the special librarian who needs a method of handling his literature collection that will cover his specialty in detail without scattering it throughout a large mass of extraneous subjects. He must have something compact, concise, easy to understand, and easy to use.

The authors point out that special librarians, even though primarily concerned with metallurgy, usually handle a large amount of literature in adjacent fields which a specialized classification such as the ASM/SLA is not equipped to handle. A little study, I think, would show that the ASM/SLA system was specifically designed to permit expansion in a number of different directions. Whilst detailed breakdowns in these other directions are not provided, the capacity to include them is inherent in the system, the philosophy being that if the large bulk of metallurgical detail is provided the preparation and addition of further detail by the individual to suit his own needs would not be too much of a chore. This has already been done in the library of the Kaiser Aluminum and Chemical Corporation, which added sections on remelt practice and on chemistry, and by the U.S. Atomic Energy Commission, which added a section on equipment (nuclear reactors), another on ceramic processes, and still another on general materials.

An idea was offered some time ago by Dr. J. E. Holmstrom, secretary of the UNESCO Advisory Committee for Documentation in the Natural Sciences. He suggested the grouping of references under 'short' U.D.C. numbers without necessarily using extensions of the decimal numbers for indexing the individual items. Detailed indexing could be provided by some other scheme such as ASM/SLA. This might be a useful expedient if U.D.C.'s concept of the word metallurgy were more in keeping with the general interpretation of the term today. It is my belief that the British Iron and Steel Institute, Jernkontoret, and the Verein Deutscher Eisenhüttenleute would do the profession a considerable service by urging the redefinition of the term 'metallurgy' in U.D.C. to broaden its coverage beyond the refining and extraction of ores; in short to make it mean approximately what it means in 1955 rather than what it did mean nearly a century ago.

It might be interesting to note that since the above comments were written, a committee has been appointed by the American Society for Metals to work jointly with the Committee on Special Classifications of the Special Libraries Association on a project to revise and expand the ASM/SLA Classification. Two meetings have been held and consideration given to several changes in the classification which will correct some inconsistencies and provide for expansion in some of the newer fields of science. For example, nuclear properties, titanium, and some of the rarer metals have achieved importance in the five years since the classification was first published. Subject breakdowns will be provided for such new fields as these without disturbing the framework of the classification to such an extent that existing files will be invalidated. Additional detail will also be provided in other scientific fields related to metallurgy. Opinions, criticisms, and suggestions would be most welcome and should be addressed to the secretary of the committee, Mrs. Marjorie R. Hyslop, American Society for Metals, 7301 Euclid Avenue, Cleveland 3, Ohio, U.S.A.

AUTHOR'S REPLY

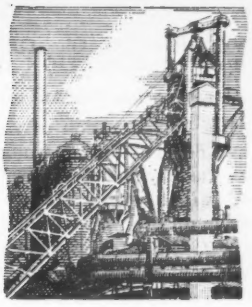
Mr. **J. P. Saville** wrote: Mrs. Hyslop's comments are interesting; but the many users of the U.D.C. have found that no serious difficulty arises from the 'scattering' of subjects related to metallurgy among various sections of it. This distribution is inherent in the universality of the system and, as stated in the paper, this universality is considered to be well worth the minor difficulty of 'scattering.' Furthermore, the system is reasonably complete and procedure has been established by means of which extensions and alterations are made uniformly by international co-operation; the confusion which may arise in the ASM/SLA system and procedure, if various individuals incorporate the same subjects into the system under different symbols, is largely avoided.

It would not be hard to rename U.D.C. 669 as 'Extraction Metallurgy'; the list of 'Allied Subjects' given in the preamble to the 669 schedule already indicates that its scope is no more than this. However, it is not possible to redefine the word 'metallurgy' itself in any simple form. Furthermore, it would be unwise to attempt to attach specialist classifications, such as ASM/SLA, to the main U.D.C. numbers such as 669, as Dr. Holmstrom has frequently suggested; this would immediately destroy the universality of the U.D.C., and lead to the spreading of similar concepts over many varied sets of number- or letter-groups.

There is a place for U.D.C. and another for ASM/SLA; to attempt to link them in this fashion will not satisfy the users of either. Far more useful would be the preparation of some form of concordance between the systems such as is already proposed between the U.D.C. and the classification used by the International Institute of Welding. It is on these lines, rather than on canvassing the merits and demerits of particular systems already in widespread use, that metallurgical documentation must advance.

AFFILIATED LOCAL SOCIETIES

Lincolnshire Iron and Steel Institute



Some Design Problems of the 'Seraphim' Plant

By I. M. Kemp

SYNOPSIS

The *Seraphim* extensions to the South Ironworks of the Appleby-Frodingham Steel Company, Scunthorpe, consisted of two blast-furnaces, a new turbo-blower plant, and an ore preparation plant, which included equipment for ore crushing and four sintering machines.

The project was authorized in September, 1951, licences to proceed were granted, and site work began in January, 1952.

The first turbo-blower and two boilers were commissioned in December, 1953, the ore crushing plant in February, 1954, and *Queen Anne* blast-furnace was blown-in on 1st March, 1954. *Queen Victoria* furnace was blown-in on 29th July, 1954, with the second turbo-blower and the four sintering machines in commission. The third and fourth turbo-blowers were commissioned in December, 1954, and June, 1955, respectively. 1153

VARIOUS ASPECTS of this project have already been described[1–5]; in this paper an attempt has been made to explain the problems which were presented and to show how the layout and design developed.

The ore preparation plant presented the most novel problems which were peculiar to this district and to the materials which had to be used, so this section is dealt with in most detail.

PREVIOUS DEVELOPMENT OF SOUTH IRONWORKS

The *Seraphim* project was preceded by extensions under the code name *Apex*, and the two previous stages of growth of the plant are shown in Fig. 2.

The original plant,[6] which was commissioned in 1939, had two 22-ft. hearth (later enlarged to 25-ft.) furnaces, three gas blowing engines, eight ore beds, two crushing plants, two Northants ore dryers, and two sinter machines, each with 16 windboxes. South of the area shown there was a 12,000,000-gal. reservoir, ore and other material sidings, and an ore railway from the mines, bridged at two points. On the west it was bounded by a coal railway leading to the coke-oven plant of 66 ovens which was built at the same time to the north. On the adjacent area to the east the ore was still being mined.

The *Apex* extensions included:

- Two ore beds
- Four dryers, for drying all the Northants ore before screening it, instead of the previous practice of drying the fines only
- Tertiary crushers for Frodingham and Northants ore, which reduced the ore for the sintering plant to below ¼ in.
- A rescreening station for Frodingham lump ore, between the bedding plant and the furnaces
- A new coke-grinding plant and an extension to the sinter materials building
- Extensive 'mixing' equipment for the sinter mixture
- Two sintering machines, each having 20 windboxes
- A return fines cooling and controlled feeding-back system incorporating a 1000-ton surge bin
- Coolers for sinter, with the object of cooling it by air.

It will be seen that nearly all the space on the ore preparation plant side had been taken up.

The *Apex* scheme also included a second battery of 66 coke ovens, and in the early stages it visualized the building of two blast-furnaces. These furnaces were deferred for further consideration—hence, the *Seraphim* project.

THE SERAPHIM PROJECT

In April, 1951, work began on plans and estimates for blast-furnace and ore preparation plant extensions, on various alternative lines. Experimental work was still in progress on the furnaces and sinter plant, so that the exact plant requirements were not known. It was, however, certain that a complete new ore-crushing plant and a sintering plant would be needed, and a new site had to be found for these which could be linked up with the *Apex* plant and with the furnaces.

The site chosen (on the south-east of the ironworks) was still being worked as an ironstone mine, but the mining company were able to release it by accelerating their rate of working here. This also permitted the removal of the railway which blocked extension to the south on the blast-furnace area.

This paper was presented at a meeting of the Lincolnshire Iron and Steel Institute held on 10th January, 1955.

Mr. Kemp is Chief Designing Engineer of the Appleby-Frodingham Steel Company.

DEVELOPMENT OF GENERAL LAYOUT AND BRIEF DESCRIPTION OF THE MAIN UNITS

Ore Preparation Plant

After consideration of various alternative schemes it was decided that it would be preferable to use the new crushing plant for Frodingham ore only, and let the two existing plants continue to deal with Northants ore, as they delivered it directly into the dryer stockyard. The dryers were quite capable of dealing with the throughput for the increased production of iron, as their performance when drying the mixture of lump and fine ore had exceeded expectations. The crushing of Northants ore at the new plant would have introduced drying there, which would have meant a very costly installation. This decision was a big step forward.

This plan involved the conveyance of part of the Northants fines from the old to the new plant, and of Frodingham ore in the opposite direction. The experiments which were being made appeared to be leading towards the exclusive use of sinter on the furnaces, so that the selection of equipment and a layout to suit this method of production was a prime consideration. Yet the ability to use lump ore had to be retained, both for the transition period of getting the new plant into commission and for permanent flexibility of operation.

The layout of the plant and interconnecting conveyor system are shown in Fig. 1. The main units are:

Incoming sidings for Frodingham ore
Primary and secondary crushers and screens
Sinter plant, and a sinter conveying system leading to new high-line bins
A conveyor system to the beds and one from the beds to the *Apex* rescreening station
A conveyor system from the Northants ore dryers to the *Seraphim* sinter plant.

The finest Northants ore is retained at the *Apex* plant and the remainder is sent to the new plant, where there are greater tertiary crushing facilities.

After the *Seraphim* secondary crushers for Frodingham ore it is necessary to take out sufficient ore for the *Seraphim* sinter plant, and a screening station placed here removes fines for the *Seraphim* plant and discharges the remainder of the ore on to the conveyor leading to the bedding plant. Thus by the simple device of varying the screen mat sizes, adjustments can be made for plant requirements and for the physical condition of the ore.

The bedding plant receives the largest ore, which is most suitable for bedding, and it provides an essential surge storage capacity and also a break in the sequence interlocking system, which enables the *Seraphim* crushing plant to work independently of *Apex*.

The ore is reclaimed from the beds, sent to the *Apex* plant, rescreened, and tertiary-crushed as required. Any surplus lump ore goes to the furnaces or stockyard by the original conveyors. Existing plant has thus been utilized to full capacity.

Although the *Apex* crushing plants now normally deal with Northants ore only, one unit can still crush Frodingham ore in an emergency. A rearrangement of the screening station has simplified the handling of Northants ore and provided more liberal rescreening facilities for the reclaimed Frodingham ore. Single-deck screens are now used. Previously it had been necessary to use double-deck screens to cope with all the screening that had to be done in a limited space.

The *Seraphim* ore preparation plant has rail and road access into the main crushing building, where a 50-ton crane can be used for unloading and transfer of machinery, but this is the only railway beyond the primary crushing plant. The use of mobile cranes and lorries exclusively for maintenance purposes seemed to be a logical sequence to the great improvements made in the designs of these vehicles in recent years. Well constructed roadways are necessary, and these have been provided; in fact, the whole area has been paved. Whilst this has made it easier to keep the plant clean, it accentuated the drainage problem. After experience of the difficulty of keeping underground drain pipes clear, it was decided to experiment with a series of long soakaway channels filled with loose slag, the top few inches of which could be removed and replaced when it got clogged. The method has been very effective on this site as there is a deep porous backfill of loose slag.

The ore preparation plant is described in more detail later.

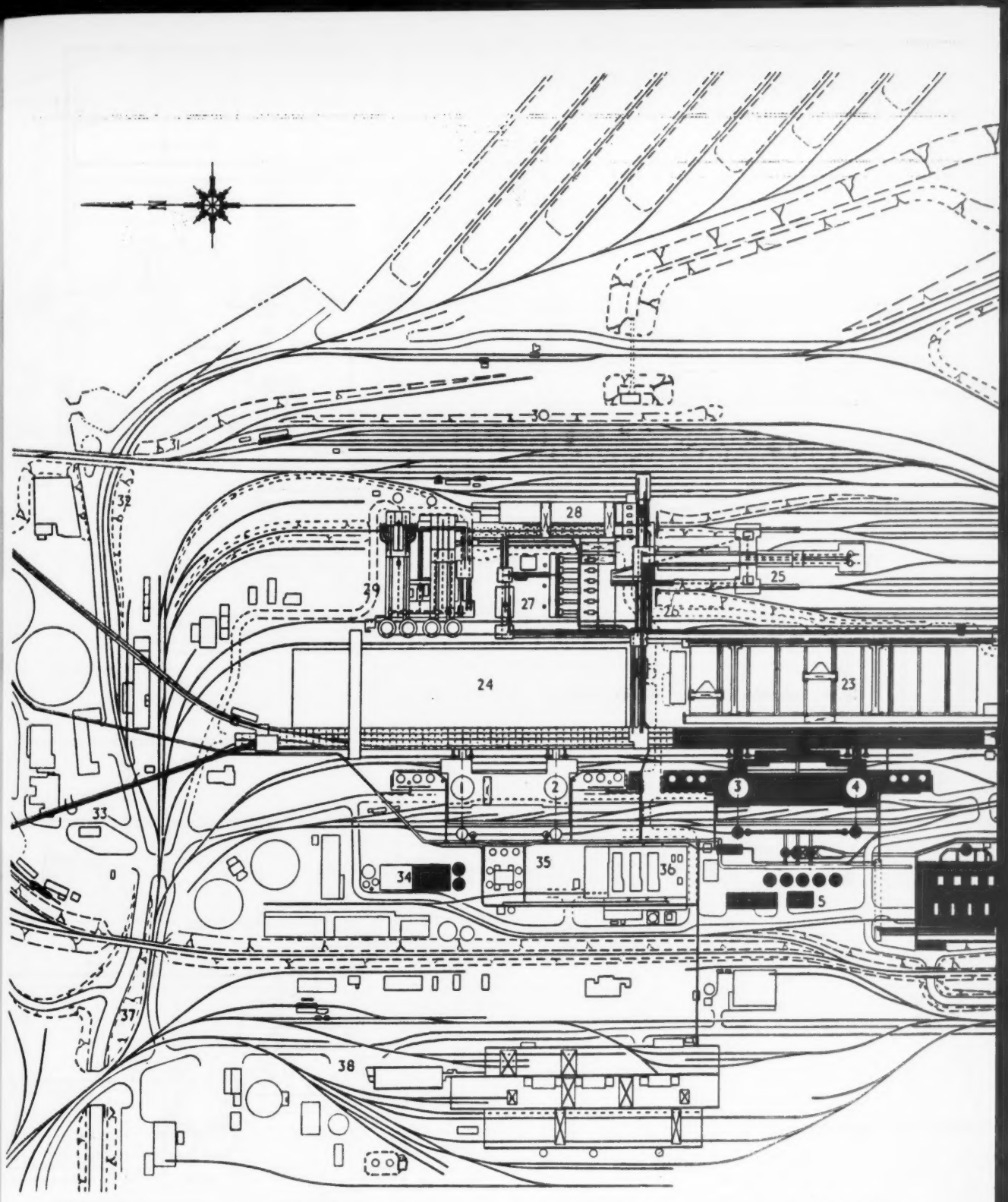
Blast-furnace Plant

The original plant layout of 1937–1939 allowed for blowing-plant extensions by gas engines at the northern end of the house, but as the space provided was insufficient for steam turbo-blowing equipment, it was necessary to extend to the south into an area which also had to accommodate the gas cleaning plant. During the early discussions on the *Apex* scheme in 1947, designs were suggested incorporating electrical precipitators on top of the gas washing towers, a practice which was being adopted in the U.S.A. to economize in cost and space. In the case of Appleby-Frodingham, the saving in space alone was very useful as extension to the south at that time was restricted by the mines railway.

The situation in 1951 was complicated by the fact that additional blowing capacity for the existing furnaces was urgently needed. One turbo-blower with two boilers would have made possible an increased output of iron and relieved the engineers of the difficulties entailed in keeping the plant going with three overloaded gas blowing engines. Whilst it was probable that the purchase of this minimum equipment would be permitted by the authorities, it was by no means certain that anything beyond this would be sanctioned. An extension of the existing house, as proposed in 1947, presented the scheme involving the least amount of labour and materials, and so this was submitted to the Ministry.

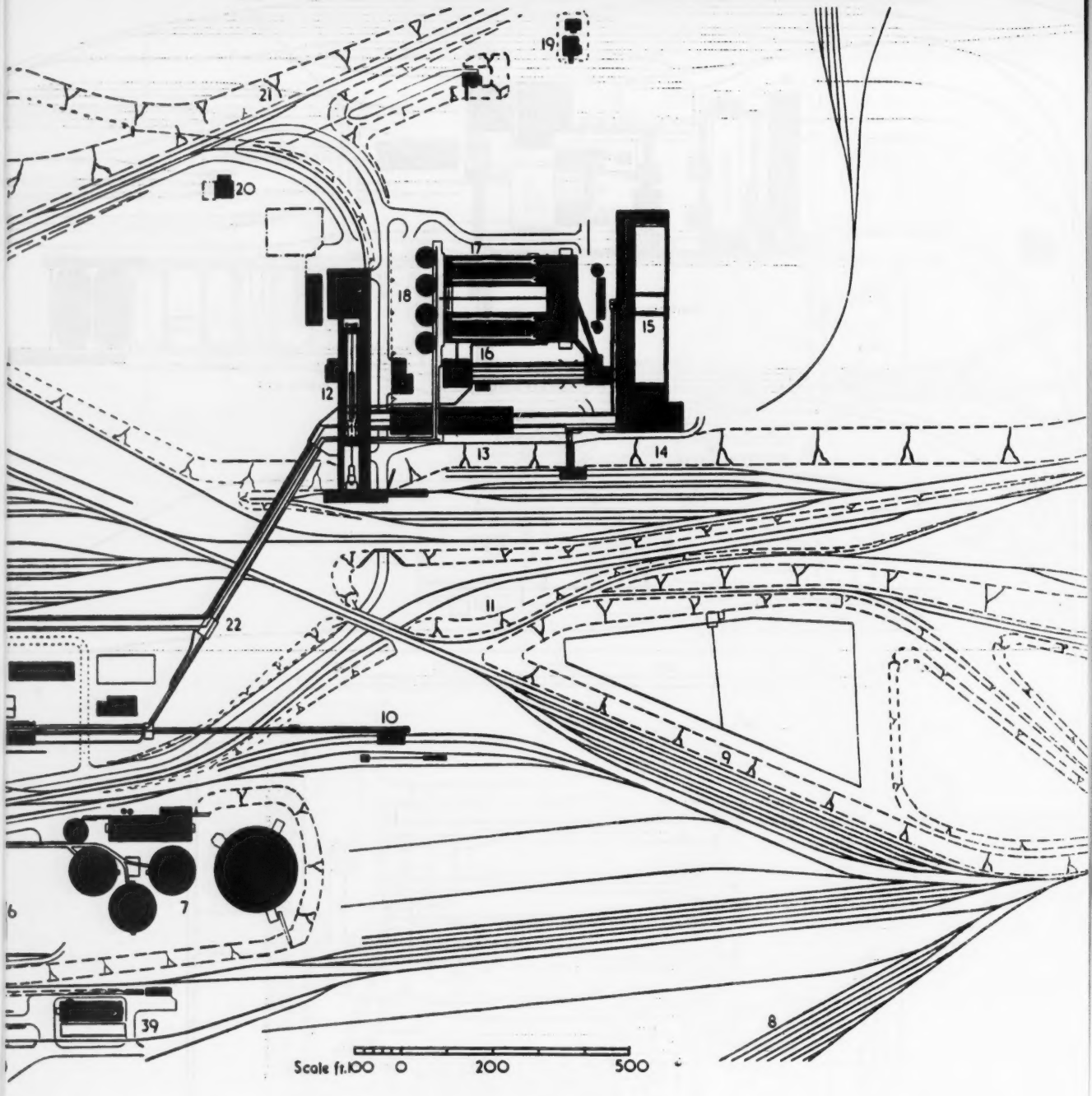
The air requirements had now been increased from the 1947 figure of 65,000 cu. ft./min. to 75,000 cu. ft./min. and the amount of gas to be cleaned had increased. The earlier scheme was still possible, but fortunately two additional furnaces were sanctioned which justified the building of an independent blowing plant, on the site which had become available.

These changes in plant and space requirements between 1937 and 1947 and again in the short time up to 1951 illustrate the need for looking far ahead



1. *Queen Mary*
2. *Queen Bess*
3. *Queen Anne*
4. *Queen Victoria*
5. Gas cleaning plant
6. Turbo-blower plant
7. Circulating water plant
8. Reception from main line
9. Northants ore sidings
10. Purchased coke reception
11. Slag route to bank
12. No. 3 ore crushing plant
13. Tertiary screens and crushers
14. Coke pulverizing plant
15. Sinter materials storage
16. Primary mixers
17. Sinter plant (*Seraphim*)
18. Sinter coolers
19. Circulating water plant
20. 33-kV substation

Fig. 1—General plan of present plant



21. Frodingham ore route (S)
22. Interconnecting conveyors
23. Ore beds
24. Stockyards
25. Nos. 1 and 2 crushing plant
26. Rescreening station
27. Northampton ore driers
28. Sinter material preparation
29. Sinter plant (*Apex*)
30. Frodingham ore sidings
31. Frodingham ore route (N)
32. Slag route to pits
33. Conveyor from coke ovens
34. Water treatment plant
35. Gas cleaning plant
36. Gas blowing engines
37. Hot metal to melting shops
38. Frodingham melting shop
39. Ironworks administration

with *Seraphim* extensions blocked in

[*Kemp*

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in these matters. Unfortunately, provision for future contingencies generally adds to the initial cost of a project.

The five electrostatic precipitators for the gas cleaning plant were placed at ground level on a line parallel with three washing towers. Many studies of arrangements of the gas mains and valves were made before a layout was reached which appeared to satisfy the Company's operating practices and safety regulations. The electrical equipment and instruments for the gas plant are completely housed in a brick building adjacent to the plant.

Blowing Plant, etc. (*Fig. 6*)

In the determination of the relative levels and spacing of the units, the need for gravity-return falls for the cooling water from the furnaces and gas plant was a factor which influenced the levels of the clariflocculators, pump house, and cooling tower, and thereby of the turbo-blower house, as the water level in the cooling-tower basement reservoir determined the condenser level. The flumes from the gas plant have a direct route to the clariflocculators, and the other units are conveniently placed. Having a large open space at the blower-house basement level with the operating floor at ground level has proved to be convenient and economical.

The equipment in the turbo-blower and boiler house is of a complex character incorporating the work of many specialized firms, and the selection and arrangement of this equipment presented many problems which are beyond the scope of this paper.

There are four John Thompson water-tube boilers each rated at 85,000 lb. of steam per hr. at 450 lb./sq. in. pressure and 760° F. Oil is used as a standby fuel, and the cleanliness of the boiler plant has justified the omission of any partition wall between the boilers and the blowers. Four Parsons centrifugal blowers are each rated at 75,000 cu. ft. of free air per min. at 30 lb. pressure, when running at 2740 rev./min. Space has been left for future development.

The arrangement of the blast mains permits any one of the blowers to blow any one of the four furnaces, and the electrically operated blast valves are arranged for emergency operation by hand from within the house. Great flexibility has been provided in the layout of the mains to allow for expansion.

A ferro-concrete natural-draught cooling tower cools water for three systems which have to be kept separate. The cooling frames and large covered storage tanks which are provided below the tower are in three sections, and each section is subdivided so that one half can be taken off for cleaning or repair. One large tower was cheaper and occupies less space than three small towers, and has the advantage that it discharges its vapour at a much higher level.

Two emergency water tanks holding 30 minutes' supply for the furnaces and gas cleaning plant, which were built into a ferro-concrete tower, presented the designers with many unusual problems.

The pump house for the blast-furnace and gas cleaning plant water contains 16 circulating pumps for the supply and return services. In recent years it has been the Company's practice to have four pumps on each service where the duty is so vital. Two pumps are normally in operation, with one standby and one available for maintenance purposes. In addition, the usual practice of duplicate electric feeders has been followed.

The sludge from the gas cleaning plant is removed in three clariflocculators, which are the first built in a British steelworks.

Blast-furnaces

Many changes were necessary to the previous designs for the furnaces, stoves, and stock house, to meet the new furnace operating technique, and to enable increased outputs to be attained. The two new furnaces have hearth diameters of 27 ft. and 28 ft. 6 in., respectively. Bosh tuyeres have been added and copper bosh coolers have been replaced by water-cooled steel jackets.

A third slag notch has been provided and, to cope with the increased make of slag, it has been necessary to arrange the ladles on three railways, despite a 60-ft. increase in the length of the casthouse.

Large piston-type clay guns have replaced the screw type.

In the layout of the casthouse the operators have been centralized in one community in a block of offices with the instrument house in the centre.

The scale cars are of a new design by which the increased capacity required has been obtained without lowering the track level and thus breaking its continuity.

Coke screening at the skip pits is done by mechanical jigging screens instead of roll screens, and spillage hoists have been provided from the pits for convenience and safety.

Globe-type drop valves on the blast mains have been replaced by straight-through hinged valves, the chimney valves are electrically operated, and the stove gas burner controls have been centralized and housed in. Improved silencers have been fitted.

A new system for bringing in purchased coke to bins over the highline and screening out the breeze has been installed.

Each furnace has supply and return cooling-water mains capable of serving both furnaces, i.e. a complete duplicate system with the necessary valves has been provided. A similar system has been adopted for the gas cleaning plant.

Figure 7 is a view of the furnaces looking north, with *Queen Victoria* in the foreground, and Fig. 8 is a view of *Queen Victoria* from the ore bedding plant.

DEVELOPMENT OF THE ORE PREPARATION PLANT

Comprehensive data were provided by the ironworks management for guidance in the layout and selection of equipment. A detailed examination of the whole of the *Apex* plant provided valuable suggestions for modifications to suit the conditions under which the new plant would operate.

A typical diagram of the general material flow giving the weekly tonnages involved is shown in Fig. 12. The *Seraphim* plant figures are on the right, *Apex* on the left, with the bedding plant in the centre.

When a preliminary layout had been prepared,

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more detailed flow sheets were made with average and maximum quantities of material in tons per hour. Adjustments had to be made in the early stages of design, as the results of experimental work became known, and the full implications of the decision to use 100% sinter burden were taken into account.

The detailed flow sheet indicating the positions of the conveyors and units of plant was completed early in 1952. As designs for 92 new conveyors and for alterations to 22 existing conveyors on the *Apex* plant had to be made, this marked a critical point of timing.

When the layout had been completed, detailed descriptions and diagrams of the material flow and the interlocks required in the new and the old plants were prepared so that the very complicated system of sequence interlocks could be arranged.

The single-way broadcast and two-way Loudaphone communication system used at the *Apex* plant had proved to be a great asset, and so it was adopted for the *Seraphim* plant, with connection between the two plants.

Figure 3 is an enlarged view of the plant. The main units are:

- Incoming sidings for Frodingham ore
- Car haul, tippler, and kick-back track
- Track brakes for full and empty wagons
- Primary and secondary crushing plant with a secondary screening station
- Screening station for Frodingham and Northants fines and tertiary crushers for both types of ore
- Coke pulverizing plant
- Materials storage and mixture preparation building
- Primary mixers
- Surge hoppers, feeding tables, and secondary mixers
- Four sintering machines and sinter coolers
- Return fines quenching mills, and conveyors leading to return fines bins
- A series of sinter conveyors leading up to bins above the furnace highline.

Ore Wagons

A large number of new wagons were required and, as in future all ore would be discharged by means of wagon tipplers, no bottom doors were necessary on these wagons. Taking advantage of the permitted axle loads of 20 tons and by using high-tensile Kuplus steel, more efficient wagons were designed having a carrying capacity of 31 tons with a tare of 8 tons 11 cwt., whereas previous wagons carried 21 tons with a tare of only 2 cwt. less; 160 of these wagons were made.

Main Crushing Plant

The output required from the primary and secondary crushing plants was known from the outset and the crushing units were of established designs. An early start was therefore made on the design of this plant in June, 1951, and discussions continued throughout the year, resulting in a contract being placed in November, 1951. Many studies were made of alternative layouts embodying the Company's operating experience before the final arrangement was agreed upon.

The plant is shown diagrammatically in Fig. 4, and the *Apex* plan is shown in Fig. 5 to illustrate the points of difference.

The side-discharge tippler for the new wagons has to turn them through 160°: i.e. it has a 70° tipping angle. The gross load is 45 tons (allowing for some surcharge) and 40 wagons can be handled per hour. The smaller wagons can also be dealt with.

The two-roll Hadfield crusher, the Ross drop-bar feeders, grizzly screens, etc., are all established designs. The problem presented was that of selecting the right units and placing them in the best positions.

Modern mining practice results in lumps of ore weighing up to 5 tons being delivered to the plant, and so an exceptionally strong first drop-bar feeder has been installed to withstand the impact of these lumps.

Figure 4 shows that the fines which pass through the drop-bar feeder, spillage, and the small lumps taken out at the two-roll screen fall on to the second drop-bar feeder which passes under the crushing rolls. The lumps that do not go through this second feeder form a protecting layer on to which the crushed ore falls.

The second two-roll screen takes out the ' middles ' and the remaining fines. The roll barrier feeds the ' lumps ' on to the conveyor leading to the secondary crusher. The middles and fines are collected on two belt conveyors which discharge them through a twin-roll barrier on to a conveyor running below the lumps conveyor.

The fines and middles are therefore being removed gradually throughout the process. They are kept separate until after the lumps have passed through the secondary crushers.

Figure 4 also shows the secondary screening station, which is referred to later. The conveyors bringing Northants fines to the sinter plant and taking sinter to the furnaces can be seen passing through this station.

Provision has been made so that this plant could be adapted for crushing Northants ore, if required, as all the crushed ore could be taken out of the system by a movable conveyor inserted at the feeding points of the secondary screens. After passing through a new drying plant situated alongside the crusher building, it would be returned to the system on the existing Northants fines conveyor.

The *Apex* plant is shown in Fig. 5. As this plant regularly deals with more than its specified output, the comments which follow are not an adverse criticism. Operating experience has, however, shown that the crushing rolls have a potential output greater than the feeding and conveying system.

There is a deliberately placed restriction in the flow from the first drop-bar feeder to the crusher, and the space and equipment below the crusher are insufficient to cope with large surges that can occur under certain conditions.

The crushers discharge on to four-roll grizzlys, after which there is a belt conveyor which carries all sizes of ore when the plant is crushing Frodingham ore. The right-angle turn between this belt and the next is a troublesome point which has been eliminated at the new plant. When Northants ore is being crushed, the fines removed at the drop bar feeder are taken away to the dryer stockyard by a separate belt. This dates from the original plan of only drying the fines, but it is still a convenient arrangement.

Fig. 6—Turbo-blower house, clariflocculators, water tower, and pumphouse

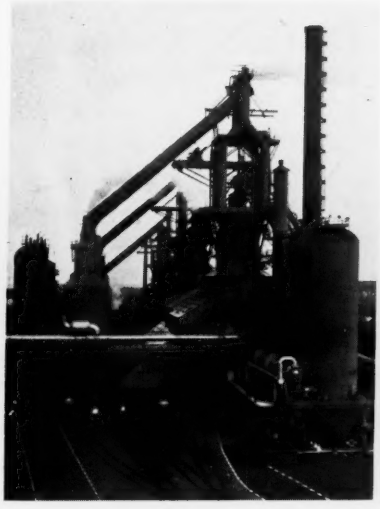

Fig. 7—View of the blast-furnaces, with *Queen Victoria* in the foreground

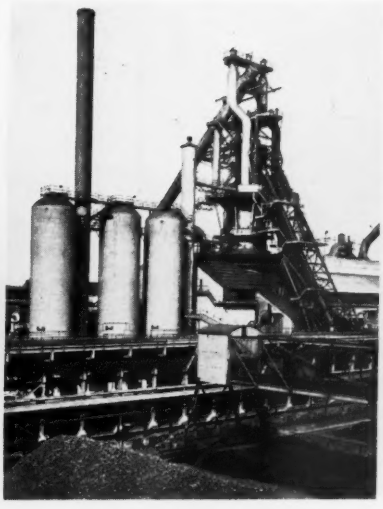

Fig. 8—View of *Queen Victoria* from the bedding plant

Fig. 9—*Seraphim* secondary screens: view looking towards secondary crushers

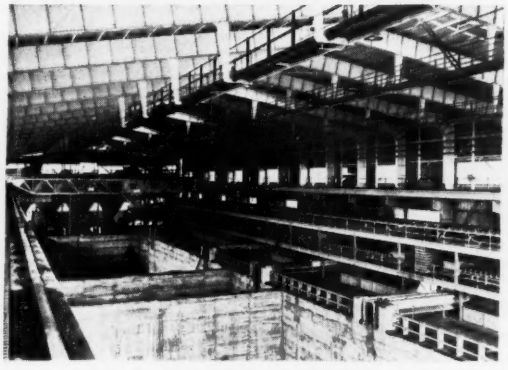

Fig. 10—Sinter materials storage building

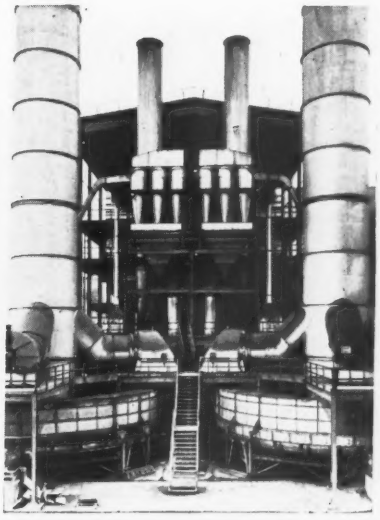

Fig. 11—Sinter coolers and dust extraction plant

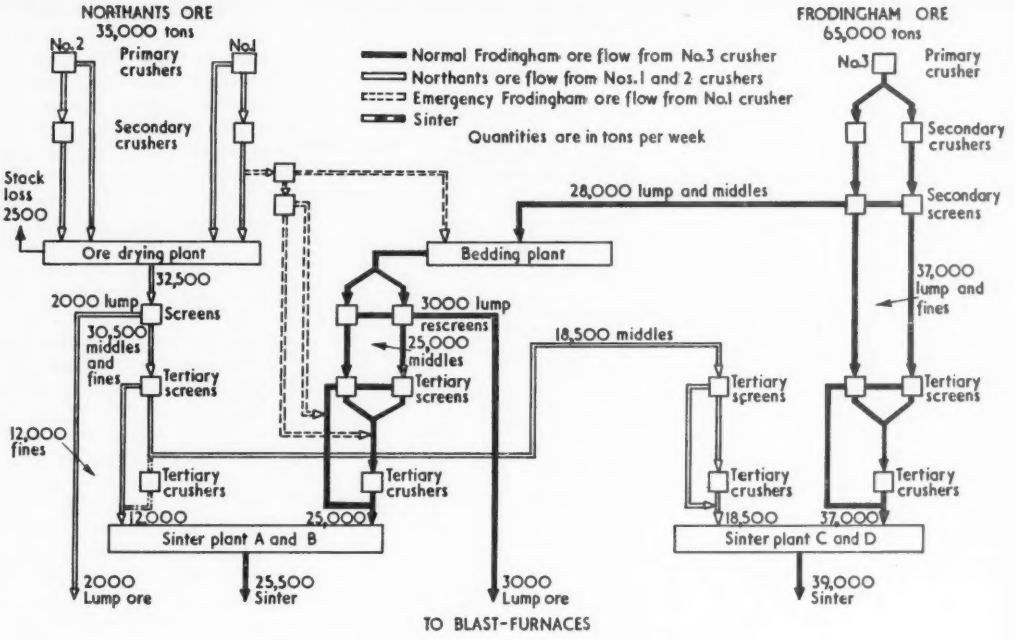

Fig. 12—Diagram of material flow

Returning to the *Seraphim* crushing plant, Fig. 9 shows the secondary screens and is a view looking towards the secondary crushers.

Secondary Crushers

Two 5½-ft. Symons cone crushers are used for secondary crushing and the feed from the single central belt can be split between the two, or all of it can be fed into either crusher by the use of a movable feed box.

The undersize which by-passes these crushers can be similarly placed upon the appropriate crushed ore conveyor, by means of a movable feed box and two short conveyors. This is a very flexible arrangement for operating and maintenance purposes.

Screening Station

Experiments with gas and electrically heated screens at the *Apex* plant and a study of the efficiency of screens arranged in parallel and in tandem showed that two gas-heated single-deck screens in tandem would give the best results, and also that two such banks of standard 14 ft. × 6 ft. screens would be necessary at the secondary and tertiary stations.

This fitted in with the use of two secondary crushers and permitted this part of the plant to be split into two sections which could be operated together or independently.

The handling of the fines from the two banks of secondary screens presented an interesting problem. They had to be collected from the two large areas under the screens, and delivered to the similar banks of tertiary screens situated at right-angles in another building.

It was desirable to avoid the use of any flop gates or chutes. The solution, which can be followed from Fig. 4, lay in the use of wide collecting conveyors under the screens, discharging directly on to a cross conveyor leading to one bank of tertiary screens, or on to short movable conveyors which could be interposed and which discharged on to a second cross conveyor leading to the other bank of tertiary screens. The arrangement gives great flexibility of operation.

Figure 13 shows diagrammatically the longitudinal section from the main crushing building through the tertiary screens and tertiary crushers, and up to the coke pulverizing building. Two views are given, one through the Frodingham ore line and the other through the Northants line.

The tertiary screens for Northants ore are hooded and provided with dust extraction pipes. The two pairs of screens for Frodingham ore are gas-heated. The provision of hoods and dust extraction for the Frodingham ore screens is being considered, as under some conditions it is nearly as dusty as the dried Northants.

The main problem here was to collect the Frodingham fines from the large areas under four screens and deliver them on to one central belt conveyor. Wide collecting conveyors were again used, discharging on to short cross conveyors.

The tertiary crushers or hammer mills at the *Apex* plant, which have a moving breaker plate, give a satisfactory product, but the fines, which are thrown against the back of the casing and the vertical face of the hole in the foundation, tend to build up into a hard mass which has to be chipped away frequently.

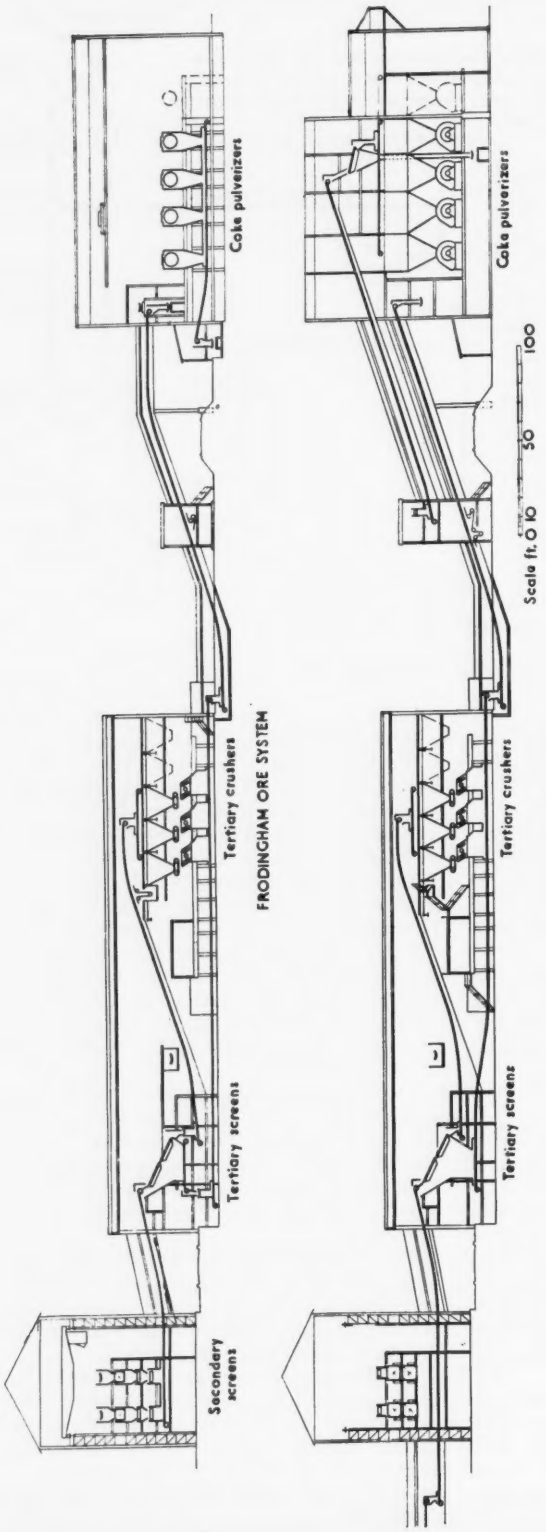

Fig. 13—Layout from primary crusher building, through tertiary screens and crushers up to the coke pulverizing plant

Extended rear ends with moving back plates had been used in such mills, and it was thought that they would be successful with Appleby-Frodingham materials. This design was therefore adopted for the *Seraphim* mills, and one of the *Apex* mills was converted to get operational experience.

Figure 14 shows the *Seraphim* tertiary crushing plant. The mills are placed further apart here than at *Apex*, permitting the provision of a very free exit for the material by bevelling the hole in the foundation.

Large surge bins fed by shuttle conveyors are provided over the crushers. The ore is fed into the mills by wide plate conveyors so that the feed is distributed uniformly over the width of the mills, thus reducing hammer wear and increasing the output.

The conveyors which bring the undersize from the tertiary screens pass below the hammer mills and pick up the crushed material. Dust-extraction connections have been provided here.

Sinter Materials Storage Building

The design of the equipment in this building presents a radical departure from the *Apex* layout. The elimination of the railway made this possible.

On the cross-section shown in Fig. 15 it will be seen that the incoming conveyors run close to one side and that there is nothing to obstruct the movement of the crane grabs from the pits to the bins.

Delivery to the pits is by means of short cross conveyors, which are run at fast speeds so that they throw the material into the pits whilst the head pulleys are kept in ambush. There are two of these to each ore pit to assist distribution.

Figure 15 also illustrates the portal-type building with steel plate roof, and the use of a ferro-concrete structure for carrying the steel bins. The nature of the site made it convenient to provide a basement

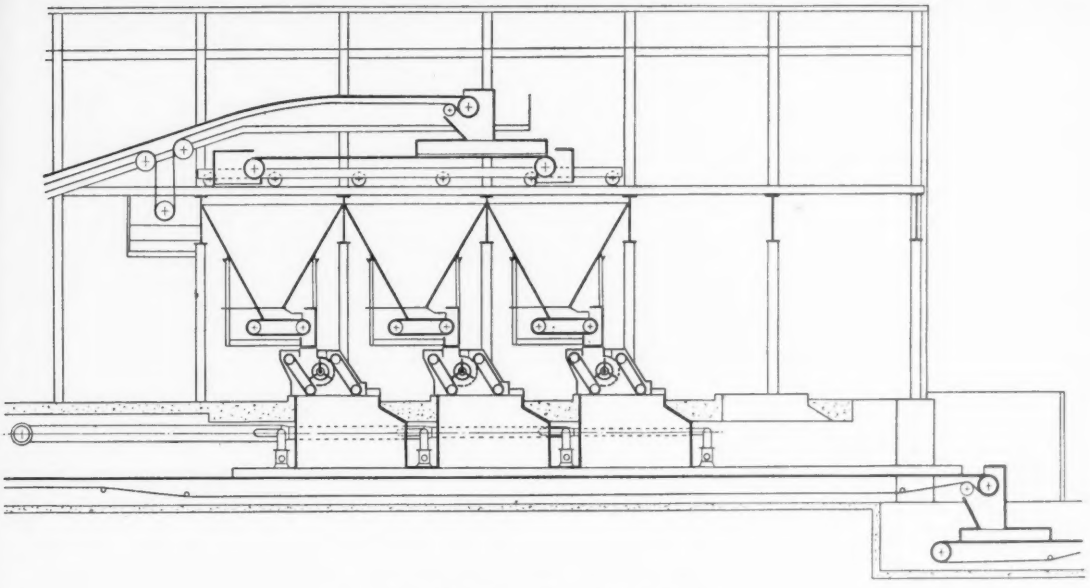

Fig. 14—Tertiary crushing plant

the whole length of the building for housing electrical equipment.

The layout is illustrated in Fig. 10, which shows the incoming ore conveyor galleries on the right-hand side. Distribution to the steel bins is by means of shuttle conveyors which, at the end of their travel, automatically discharge on to the cross conveyors. The use of belt trippers has thus been avoided.

Grab Cranes

The *Apex* grab cranes are of 12 tons gross capacity. By having the *Seraphim* grabs constructed of high

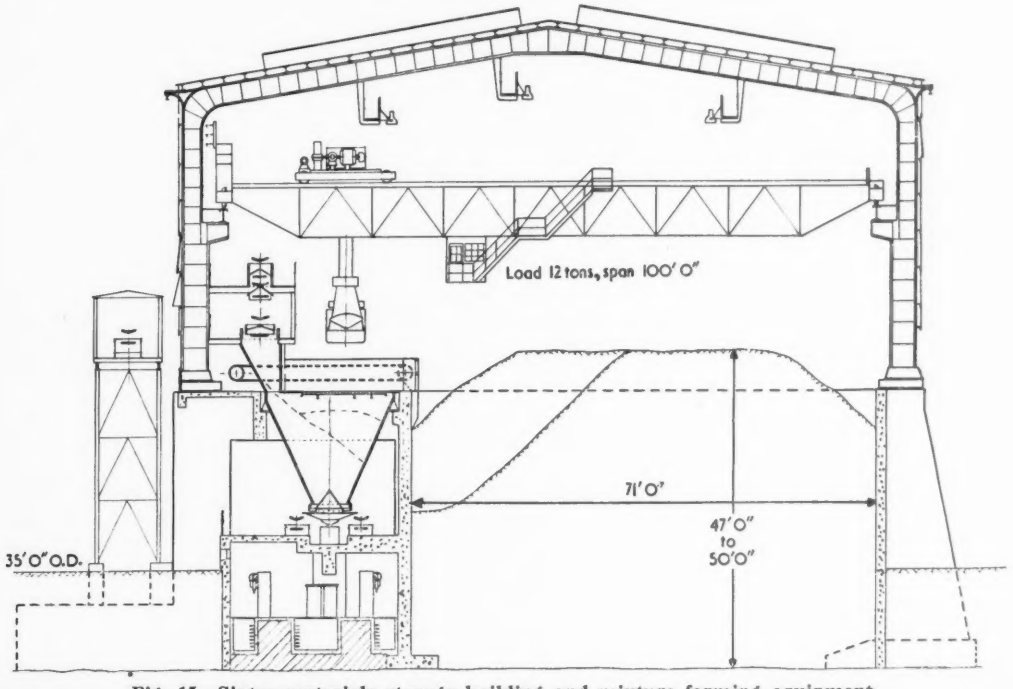

Fig. 15—Sinter materials storage building and mixture-forming equipment

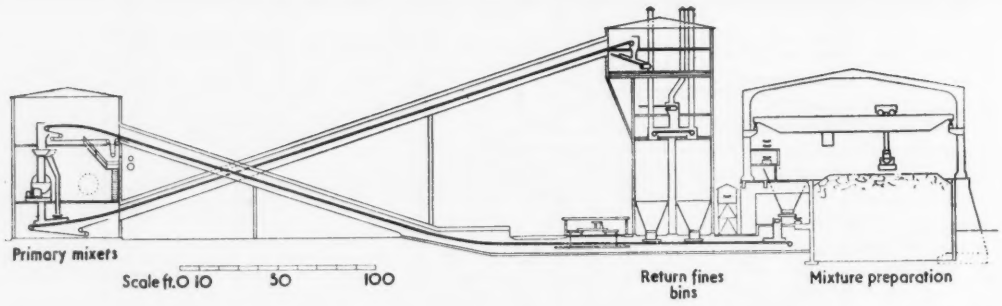

Fig. 16—Conveyor system up to the primary mixers and the junction house of conveyors leading to the sinter machines. Return fines bins are also shown

tensile Fortiweld steel and making some improvements to their design, their carrying capacity was increased by over 20% without increasing the gross load on the crane. Also, by increasing the span by 25% (from 80 ft. to 100 ft.), 40% was added to the stock-pit capacity, which then gave the storage required within the length taken up by the steel bins. The position chosen for the crane cab gives a good view of all operations. The cranes have tapered tread wheels.

Mixture-forming Equipment

Lengthy trials had been made at the *Apex* plant of various designs of orthodox bunker mouths, some of which were working satisfactorily elsewhere but would not work with Appleby-Frodingham materials and conditions. Designs incorporating skirt adjusting methods and dual plough gear which satisfied the operators were finally developed, and these designs have been used at *Seraphim*. The feeder tables themselves are of the original 1939 design. They have a conveyor on each side serving two sinter machines.

The coke bins are rectangular in form and are situated between the Northants and Frodingham ore bins. The coke is withdrawn from the bins by Lea cubi-meters. The speed of the cubi-meter belts is under the control of the sinter-machine operator, but adjustable gates are also provided.

The mixture-feed control is similar to the *Apex* system. The operator at the tables can adjust the height of the skirt plates and the position of ploughs but not the speed of an individual table. The sinter-machine operator can vary the speed of all the tables together to suit the rate of consumption of the sinter machine, without upsetting the proportions of the mixture.

Figure 16 shows diagrammatically the conveyance of the mixture to the primary mixers and to a junction point above the return fines bins, from which it is taken to the sinter machine building. The bins are placed in this position so that the fines can be delivered by feeding tables on to the mixture belts, and thus complete the mixture, except for water. This system is described later.

The sinter mixture and the return fines are weighed on three belt-weighing machines, and the weights are transmitted to the machine control rooms. Previous unhappy experience of the effect of dust on weighing machine mechanisms has resulted in these being placed in totally enclosed houses. Two of the machines are placed just beyond the return fines feeding tables.

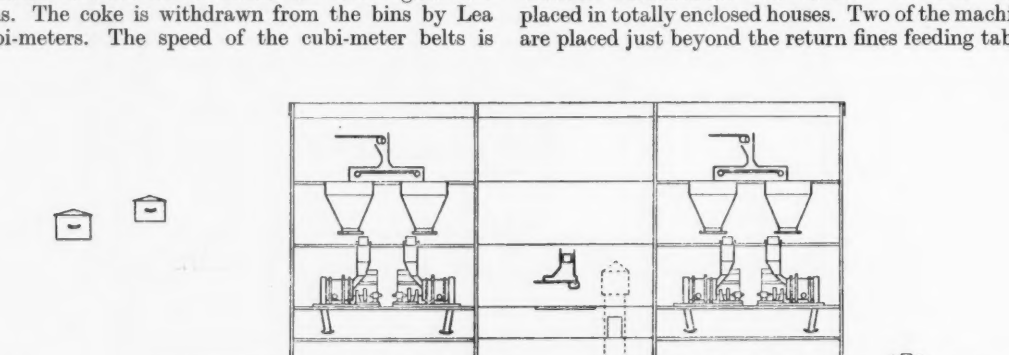

Fig. 17—Surge bins, secondary mixers, etc.

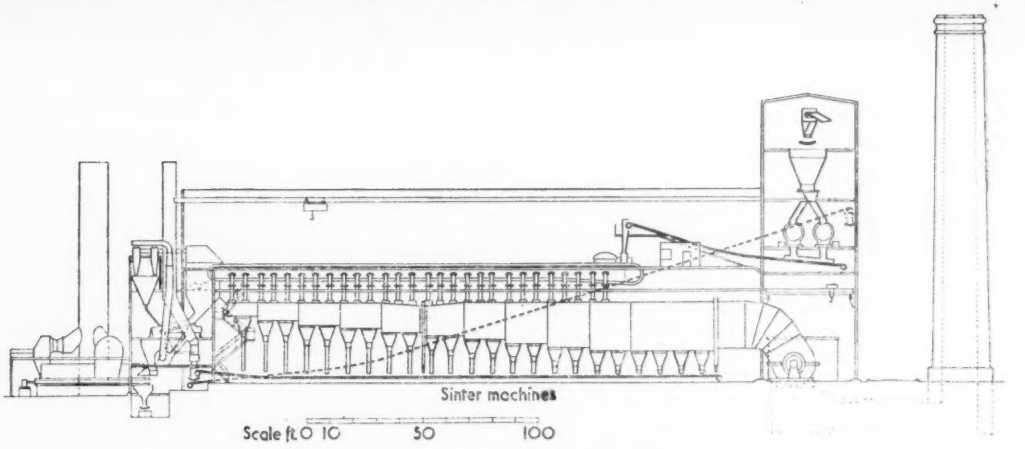

Fig. 18—Sinter machines and coolers

The primary mixers installed in the 1939 plant had revolving drums with single-paddle shafts. At *Apex*, double-paddle shaft static mixers were tried. They gave no better mixing, the materials tended to be compressed into a solid mass, and the paddle wear was high. As better mixing was needed for *Seraphim*, revolving-drum machines with double-paddle shafts were used. As the machines were somewhat experimental, and yet the risk of ordering ten machines had to be taken (including primary and secondary mixers), additional pulleys were made for trying various relative speeds of paddles. The double-paddle machines have improved the quality of mixing.

Surge Bins and Secondary Mixers

From the junction on top of the return fines bins the two conveyors go on to the highest point of the system. At this point the mixture on each of the two conveyors has to be split into two parts without any segregation taking place, as each conveyor serves two sinter machines. This has been done by making each conveyor discharge on to a short reversing conveyor, which feeds a pair of surge bins. The short conveyor is automatically reversed at intervals of about $2\frac{1}{4}$ min., and so segregation of material is impossible. Each surge bin serves a sinter machine and provides a buffer between the feeder tables and the machines. It has been found that segregation occurs if one surge bin serves two sinter machines.

Below each surge bin a feeder table serves either of two secondary mixers, similar to the primary mixers, but smaller, through a movable feed box. From here the mixture is conveyed to the swinging spouts at the sinter machines.

A general view of this equipment is shown in Fig. 17.

Sinter Machines

Figure 18 is a longitudinal section through the sinter machine building. The machines are Head-Wrightson–McKee design with 28 windboxes and pallets 6 ft. wide and 14 in. deep. The main points of difference between the *Seraphim* machines and the two latest *Apex* machines are as follows.

The *Seraphim* length over windboxes is 40% greater: 168 ft. against 120 ft. The fan capacity has been increased, suction from 21 to 26 in. W.G., volume from 200,000 to 300,000 cu. ft./min., and motor power from 1200 to 2210 h.p. This motor power exceeds the present requirements as provision has been made for increasing the fan capacity by adding to the impeller diameter if required.

Investigations on the *Apex* plant by a research group[7] resulted in a fan design with back-swept blades being adopted with a guaranteed efficiency of 75·4%, whereas the previous efficiency was 59%.

These researches also showed that cyclones could be eliminated without detriment to the fans and with a considerable saving in power consumption. The dust collecting mains are very large at the fan end and a length is provided there to form a dust settling chamber. Owing to their length an additional expansion joint was necessary near the centre, and this had to be designed to fit in the limited space available. The mains are lined with Nori bricks, as at *Apex*.

As the sinter mixture is brought up outside the main building, the central space between a pair of machines is free of obstruction, and it has been possible to provide hatchways so that $7\frac{1}{2}$-ton electric cranes can lift materials up to the machine floors. Also, the view of the machines from the control rooms is unobstructed.

Sinter Cooling

The research work at Apex had shown that the best way to treat the hot sinter was to crush it, screen out the fines, and then to cool the remaining lump sinter by air, so that it could be conveyed on a rubber belt without adding any water.

By screening before cooling, the size and capital cost of the air-cooling equipment and the power consumption were reduced and the problem of dealing with dust emission was eased.

Discussions with the Lurgi Company and inspection of their experimental straight-line cooler resulted in their being asked to design a circular cooler, incorporating the louvred tray features of their straight-

line coolers. The cooler was to be preceded by a crusher and screen. This sinter-cooling plant was a vital feature of the project for which experimental results and future problems had to be assessed. The improved quality of sinter to be obtained by air-cooling was a key factor in estimating the operating results of the new furnaces which were being built. Only confidence in the thoroughness of the experiments justified proceeding with the construction of previously untried plant and also taking the apparent risk of trusting so much to sinter being carried on rubber belts. The Lurgi designs were accepted and these machines, known as the Lurgi–Frodingham coolers, are proving to be very successful.

The screens and feeders to the coolers are of the mechanically operated vibrating type. Powerful dust-extraction systems have been installed by the Buell Company, serving the points where dry sinter is being handled, and it is felt that a great improvement has been made in dust elimination in this area. Figure 11 shows two coolers and the dust extraction plant.

The cooled furnace sinter is discharged into small hoppers from which electric vibrating feeders distribute it on to the first conveyor of the system leading to the furnaces. There are four conveyors between this point and the bins over the high line, the total length being 1735 ft. and the rise 146 ft.

Return Fines

It was decided to continue to cool the fines by water, as there was no metallurgical objection. To cool them by air on machinery similar to the main coolers would have been very expensive and there would be a serious dust problem to meet. The stationary double-paddle quenching mills at *Apex* were effective for this purpose, and so they were adopted with some improvements to facilitate maintenance. Large chimneys have been placed over the mills to take away the vapour. To minimize deposition of the fine dust inevitably carried up the chimneys by the vapour, the hot products from the Buell system are discharged into the chimneys.

The sinter fines are conveyed to the quenching mills by electric vibrating feeders. The variations that occur in the quantity and the nature of the fines make this a difficult load for the feeders to cope with, and experiments are still proceeding.

From the quenching mills the fines are taken by belt conveyors to the return-fines bins, which have a capacity of 2000 tons. The vapour rising from the conveyors (particularly at junction points), condensation, and scraper maintenance problems make this system the most troublesome section of the plant.

Both the air-cooling and the water-cooling system for return fines have their objectionable features. Perhaps the best solution could be found in a combination of air and water, or a reasonable air-cooling system for fines may be developed.

Water Cooling, etc.

Experience at the *Apex* plant during hot weather showed the need for a cold supply of water for the ignition hoods, motors, fans, etc. A cooling tower and recirculating system has therefore been provided. Plant drainage water is used for process purposes and overhead tanks have been provided to give a constant pressure at the mixer valves, thus facilitating accurate control.

Coke Pulverizing

Rod mills have again been adopted for coke pulverizing, but the cost of the installation was reduced by using larger mills giving nearly double the output, i.e. an increase from 6 to 10–12 tons/hr. Maintenance facilities have been improved by the provision of a 25-ton electric crane over the mills. The coke is elevated by belt conveyors instead of a skip hoist, so that a continuous feed to the screen is obtained.

Guarding of Machinery

The standard required for the guarding of machinery, and particularly of conveyors, is extremely high. Whereas in many cases the best results are obtained if a guard expert measures up and makes the guards after the plant has been erected, this is a slow process which necessitates a lot of temporary guarding. To cope with the work it was necessary to have a number of draughtsmen measuring up on site, and the provision of suitable guards was a troublesome problem to which a great deal of thought had to be given by all concerned.

The Chairman of The United Steel Companies, Ltd., Sir Walter Benton Jones, has said that "*our works should be places fit to live in for everyone who finds occupation there.*" In the planning of this project an endeavour has been made to provide a plant which can be maintained at this standard.

Acknowledgments

The consulting engineers for the project were: The Parolle Electrical Plant Company; Ashmore, Benson, Pease and Co., Ltd.; Head Wrightson and Co., Ltd.; and Ross Engineers Ltd.

An Appleby-Frodingham team, which represented the ironworks production staff, all sections of the engineering staff, and the research department, co-operated in the work, so that the design of the plant is the result of the joint efforts of many people.

The author expresses his thanks to Lt. Comd. G. W. Wells, R.N.(RET.), D.L., M.I.MECH.E., Director and General Manager of The Appleby-Frodingham Steel Company, for his permission to publish this paper.

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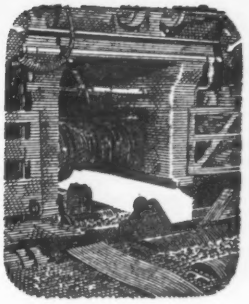
IRON AND STEELWORKS ENGINEERING

The Iron and Steel Engineers Group



Organization for Maintenance

By J. L. Gaskell

SYNOPSIS

The paper describes an organization which is real and exists. Methods of maintenance management operated are stated, two examples of inspection methods are examined in some detail, and lubrication engineering as a specialist service is referred to. Emphasis is placed on the magnitude, and consequently the cost, of maintenance services in heavy industry and the need for maintenance personnel to become more and more aware of the effect of their activities in the cost of the product. The problem of spares stock investment is stated.

The author has been careful to avoid theorizing about maintenance work and hopes that the paper may serve to stimulate a discussion based on the realities of experience. 1195

Introduction

THE OBJECTIVES of a maintenance organization have probably been stated many times but it would seem appropriate to commence a paper on this subject with a definition of these objectives as follows:

- To safeguard the buildings, plant, and equipment in its care against undue depreciation or loss.
- To maintain the aforesaid assets in a state of the highest efficiency, i.e., subject to sensible tolerances for wear, " as good as new."
- To eliminate breakdowns caused by fair wear and tear (as distinct from accidental damage) by replacing worn parts before, but not too long before, they fail and at such times as to cause no loss of production.
- To foresee potential failures which are foreseeable and take appropriate preventive action.
- To repair accidental damage in the quickest and most effective manner.
- To expend the minimum amount of money in achieving the foregoing.
- To avoid locking up excessive unproductive capital in unduly large stocks of spares.

For any organization in any industry to fulfil these objectives conscientiously is no easy task and in the metal industries the difficulties are intensified by some of the severest duties which can be imposed on industrial plant, e.g. abrasion in ore-preparation plants, corrosion in pig-casting plants, shock loadings and frequent stress reversals in rolling mill equipment.

The capital cost of plant for the heavy iron and steel industry is, however, very high. Expressed in terms of capital investment per employee of all grades it may well be upwards of £5000. Larger and larger outputs are needed in order to spread the overhead costs, hence down time due to breakdown or mishap must be kept to a minimum, i.e. the availability of the plant for productive use must be high. As throughput rates increase so the effect of stoppages tends to become more serious. Hence the maintenance organization must achieve high plant availability despite the arduous service conditions.

The growth of maintenance organizations is, of course, bound up with increasing mechanization, and results in the present position that the ratio of operational to maintenance labour is approximately 3 to 2. Figure 1 shows the usage of electrical energy at Appleby-Frodingham from 1926. Whilst much of the increase from 1948–49 is accounted for by the electrification of the main drives for the Frodingham cogging and 32-in. mills, previously steam driven, it should be noted that there are no more rolling mills than in 1926 except that the 7-ft. plate mill was converted to a tandem mill in 1938. This graph does give some indication of the effect of increasing mechanization.

More and more power is being put in the hands of the operating personnel and as developments move

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in the direction leading ultimately to the fully automatic plant it seems inevitable that the ratio of maintenance to operating personnel must increase.

The cost of maintenance is already a very important factor in the cost of the final product, and as indicated above may be expected to become increasingly important. It must therefore be expected that increasing attention will be focused upon the costs incurred in maintenance, consequently all with executive authority in this field must make themselves increasingly aware of the factors which influence costs and how these factors may be controlled.

THE BASIS OF THE ORGANIZATION

The fundamental principle of the maintenance organization at Appleby-Frodingham is a division into areas such that for each area a responsible engineer can be expected to be in reasonably close touch with all directly concerning his function that is going on in that area. This engineer is known as a *plant engineer*.

It is evident from papers and discussions on this subject of maintenance work that the term plant engineer is applied in the industry to a wide range of responsibilities and it is therefore considered necessary to enlarge upon the general definition. The works of the Appleby-Frodingham Steel Company, although in total an integrated works, can quite properly be regarded as a group of works, each component representing what in many spheres of activity would be regarded as a large works.

For example, the area of responsibility for the Appleby Steelworks plant mechanical engineer covers:

Melting shop with seven 250–300-ton O.H. tilting furnaces and two 500–600-ton mixers
Basic slag plant
Stripping facilities
Soakers
42-in. slabbing mill
Reheaters
10-ft. plate mill, 7-ft. plate mill } and associated normalizing, flattening, slitting, shearing, and loading facilities.

Clearly the plant engineer could not be in intimate touch with all the mechanical engineering activities for such a magnitude of plant and in this particular case—leaving aside inspection for the moment—the plant is further sub-divided into six spheres of responsibility for assistant engineers, all, with one exception, on an area basis. The exception is on a functional basis in respect of overhead cranes. Since there are 55 overhead cranes, chargers, and strippers in this area it is considered there is full justification for an assistant engineer devoting his individual attention to these items of plant.

Each plant engineer has the appropriate strength of day-working and shift-working fitters, pipefitters, riggers, greasers, and labourers together with corresponding day and shift foremen, clerical staff, and one or two plant draughtsmen. He also has a small emergency or 'first-aid' workshop equipped with a minimum of machine tools.

Electrical maintenance work is organized on exactly similar lines but, because of differences in volume of work involved, the areas of responsibility of plant mechanical and plant electrical engineers are not generally coincident.

Plant engineers are also responsible for plant attendants, e.g. boiler, gas-cleaning plant, motor, pump, substation, and switchboard attendants and engine and turbine drivers.

The first call on the time and resources of the plant engineer must always be the existing plant. Nevertheless, his organization is expected to be able to, and does, take in its stride a substantial measure of site work in respect of new and replacement plant. The plant engineer must also ensure that when new or replacement plant is being considered by the design organization all experience which will help in the improvement of designs is brought out. It is submitted that his responsibility as defined puts him in the best possible position to ensure the passing on of appropriate information. This applies equally to management problems in respect of men.

The plant engineering divisions at Appleby-Frodingham are as follows:

Ironworks Mechanical
- Coke-oven plant
- Ore preparation plants
- Blast-furnaces and ancillaries
- North Works power station and outlying pumping stations

Steelworks Mechanical
- Frodingham Steelworks (including United Steel Structural Company)
- Appleby Steelworks

Electrical
- Frodingham (including U.S.S. Co., central electric shop, central engineering workshops)
- Appleby Steelworks
- South Works (including coke-oven plant and Frodingham Melting Shop)
- North Works power station and primary distribution.

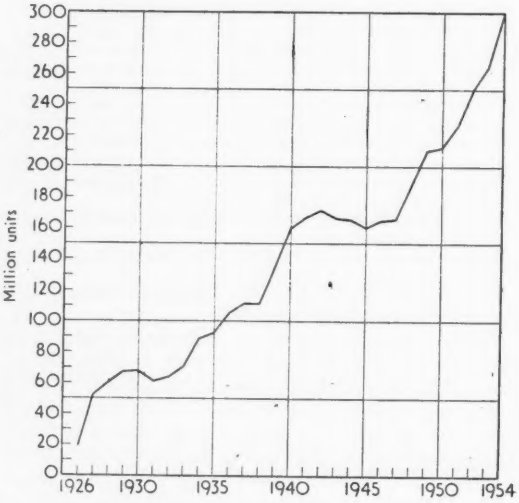

Fig. 1—Growth of units of electricity

The division into ironworks and steelworks mechanical engineering is a matter of administrative convenience and the divisions are responsible respectively to the Chief Ironworks Engineer and the Chief Steelworks Engineer, and the plant electrical engineers are responsible to the Chief Electrical Engineer.

Civil engineering is discussed later.

For any given productive unit, therefore, there are three senior officials directly concerned in the effective productivity of that unit—a production manager, a plant mechanical engineer, and a plant electrical engineer—and it is their business to work closely together in pursuance of the common objective. Differences occur, of course, and presumably always will, but these are generally resolved by discussion. In this connection a vigorous lead has been given as a matter of Company policy over the past ten years on the subject of consultation generally and at all levels and it is believed that a great deal has been achieved in eliminating the attitude of two sides in the industry—production and maintenance. If ever there was a time when a maintenance organization had to justify its necessity that time has certainly passed. Nowadays a maintenance organization must be quite sure it can justify its magnitude and its effect on the cost of the final product.

CIVIL ENGINEERING

Whether, and to what extent, a separate organization is set up to deal with civil engineering matters must clearly be governed by the magnitude of the plant and the volume of such work to be carried out. On a plant the size of Appleby-Frodingham a separate organization is certainly necessary. It operates as a general service in the charge of the senior civil engineer and is broken down into four functional branches, as distinct from the area divisions as described for mechanical and electrical engineering, each in the charge of a civil engineer. The work of this organization is roughly equally divided between maintenance work and new work.

General Civil Engineering Work

This section deals with excavations and concreting work in connection with plant modifications and new work, with general maintenance work on roads, drains, septic tanks, concrete floors, and timber and concrete cooling towers. The section is equipped with joiners' shop, two ½-cu. yd. excavators, concrete mixers, pumps, and compressed air tools, together with appropriate manning of surveyors and clerical assistance, staff foremen, joiners, concretors, and general labourers.

Railways

The fact that the works rail system extends to over 100 miles of standard-gauge track, some of it subject to very heavy axle loads, indicates the necessity for such a specialist section. Day-to-day maintenance including lubrication and de-icing of points is dealt with by small gangs headed by chargehands and located in various plant areas. Major renewals are dealt with by three mobile platelaying gangs. The trackwork is kept in good condition and derailments are notably few but the section has well-equipped breakdown vans for dealing with such contingencies and is equipped with trackshifters which are kept busy on slag disposal and stock ground railways.

The section has a surveyor, staff foremen, clerical assistance, and a substantial measure of its own labour force, the balance being made up by contract labour.

For some years now it has been the practice to plan in detail major renewals and improvements a year ahead as part of an overall renewals programme and each year an appropriate sum of money is allocated for the purpose.

Buildings Maintenance

This section deals with offices, welfare buildings, laboratories, house property, etc., as distinct from structural steelwork industrial buildings. It deals with joinery and plastering repairs, glazing, and decorating and calls upon the appropriate mechanical or electrical departments for attention to plumbing, heating, ventilating, and electrical matters. The cleaning of all windows, including the roof lights of all industrial buildings, is also dealt with by this section.

There has been a very considerable volume of new building work of this kind in the post-war years and much of the supervisory time of the section is taken up checking and progressing building contractors' work.

Salvage and Works Tidiness

In general on the works the occupying departments are responsible for cleaning and tidying in and around their buildings but may call for special assistance from this section in respect of industrial vacuum-cleaning, lime spraying, and steam cleaning of brickwork. There are, nevertheless, considerable intermediate areas in which this section has entire responsibility for tidiness. It collects all ferrous and non-ferrous scrap (other than process scrap), dismantles, breaks, burns, and sorts as necessary for re-use in production processes or in certain cases for sale. A locomotive crane equipped with lifting magnet is in constant use on railways picking up ferrous scrap.

The section looks after the grassing of embankments, weed control where necessary, and provides light-duty employment for lawns and gardens.

Additionally, there is available a civil engineer (construction) whose function is to deal with the civil engineering site work in connection with major new construction works.

ROAD TRANSPORT

In this branch of engineering it again depends very much on the size of a works how the work is dealt with. At Appleby-Frodingham the volume of work associated with vehicles and other internal combustion engine operated devices is more than sufficient to justify an organization separated from the responsibilities of the plant mechanical engineers.

This department, in the charge of the road transport engineer, is responsible for maintaining and in the main for operating the Company's fleet of cars, vans, lorries, buses, ambulances, dumpers, loaders, fork-lift

trucks, portable compressors and pumps, track shifters, and diesel grab cranes and excavators. It is provided with a well equipped modern workshop together with office block which will ultimately cater for the garaging of all the road vehicles and a separate shop in which grab cranes, excavators, and other special-purpose equipment is maintained.

Fuller details of the civil engineering and road transport organization and work appear in the special issue of the *Iron and Coal Trades Review* which will be published early in September, 1955.

GENERAL OUTLINE

It is considered desirable to include at this point a brief indication of the remaining services which are necessary to make up a complete engineering organization.

The central engineering workshops at Appleby-Frodingham clearly constitute a very important factor in the overall maintenance system. They have been fully described[1] and it is therefore not proposed to describe them here. It is sufficient for the purpose of this paper to state that it comprises a large, modern, and well equipped engineering works which carries out repairs to parts, the manufacture of replacement parts, and the manufacture of complete items of new plant. It functions, in effect, as a separate company in the charge of a manager directly responsible to the general works manager, and on which the plant engineers and the Design Office place orders. It also deals direct with the maintenance of locomotives, steam cranes, and rolling stock.

General design and drawing-office work is centralized and, in addition to its major function of layout and design of new plant, this organization does a great deal of work on the kind of modifications which arise out of operating and maintenance experience and which play a very important part in successful maintenance engineering. Specialist electrical design and drawing-office work is dealt with in a central electrical office.

The maintenance of structural steelwork including building-cladding and cleaning of roof gutters is dealt with by a separate company, the United Steel Structural Company, situated within the Appleby-Frodingham works area, as an addition to its general structural steelwork manufacturing activities.

Instrumentation and thermal insulation is dealt with by the engineering research department, which department also includes in its activities the distribution of fuels, steam, water, and oxygen. This department has full maintenance facilities in its instrument shop situated in the central engineering workshop buildings. The electrical department also disposes its fully equipped central electric shop in the same buildings.

Lubrication engineering and a specialist section of the electrical department are discussed later in this paper in relation to the general theme of the objects of a maintenance organization.

The organization described provides for generally clear-cut spheres of activity and responsibility which are well understood at all levels, and it has the essential flexibility which enables it quickly to adapt itself to any problem which may arise. It is submitted that such flexibility or adaptability is a major factor in achieving success with a large organization called upon to cope with a rare complexity of problems.

MANAGEMENT METHODS

It is not the purpose of this paper to discuss the detailed technicalities and mechanics of carrying out specific engineering maintenance jobs or the technical ingenuity exercised in doing them more quickly or better than they have previously been done, but rather to discuss the organization which brings about the conditions and the co-ordinated effort which enables these things to be done. A number of examples of such physical aspects and the effective use of modern aids have been published,[2, 3] and the blast-furnace repairs and reline times tabulated therein show the progressive reductions which have been achieved in down time for such major units of productive capacity.

The Company recognizes the immense fund of knowledge which must exist in any large body of experienced men and the need of men to know what is going on around them and why. The Company therefore operates a declared policy of joint consultation, whether formal or informal. This is of course not peculiar to maintenance activities.

In the majority of maintenance departments, formal committees on which the men are represented meet regularly to discuss delays and what can be done about them; job methods, developments, personnel matters, and in fact all matters relating to the activity of the department other than those which are customarily the function of a trade union are discussed. Clearly, in such a large organization with its diversity of interests and activities a single Joint Production Committee would have to confine itself to broad generalities, but the localized departmental committees can and do get down to fundamental detail. It is believed that these committees have been a considerable help in building up a great fund of goodwill.

In fact, committee techniques are extensively used. An example of a regular committee operating at departmental management level is the plate mills maintenance committee attended by representatives of mill management as well as the plant mechanical and electrical engineers, assistant engineers, and representatives of the central engineering workshops. Problems of site maintenance, usage of the plant, and supply of engineering materials are freely discussed, and differences of opinion are aired and generally resolved.

Safe working is just as much a maintenance function as the technicalities of its work and departmental safety committees have operated in most departments for several years with the object of getting more people directly and actively interested in accident prevention than was possible in the main works Safety Committee. It is of course not possible to evaluate the effectiveness of each separate measure directed towards the prevention of accidents but it is believed that these committees have been a considerable factor in reducing the works accident frequency rate to its present low value.

Special committees are set up as the need arises and for as long as the need lasts; for example, hammer wear in the hammer mills used in ore preparation is a very serious problem in respect of cost of repairs and renewals, and time, and a committee known as the Hard Surfacing Committee with representatives of operating department, plant engineers, central engineering workshops, and metallurgical research department meets regularly to discuss ways and means of effecting improvements and the results of metallurgical examinations and will continue to meet until the best possible solution is established.

It is not wished to convey the idea that the entire work of organization and execution of maintenance work is carried out by committee procedures but to commend them as aids, and there can be little doubt that experience of this kind of activity has proved it valuable in bringing about improved relationships in day-to-day activities both within departments and with other departments, thus facilitating the exchange of information, experience, and ideas which leads to work being carried out in the most effective way.

Indeed, a great deal of interdepartmental co-operation goes on an *ad hoc* basis as, for example, in the development of the special burners for steel furnaces for coke-oven gas and pitch-creosote firing.[4] Considerable use is also made of the facilities and knowledge of the metallurgical research department in respect of both ferrous and non-ferrous metals in the metallurgical investigation of failures and in the application, when necessary, of higher-grade materials.

At the risk of appearing trite, the importance of pre-planning cannot be overstressed. In many cases, discussions and arguments over a long period and the step-by-step compressing of time and job schedules has led to the execution of major operations in times which on first examination appeared quite impossible of achievement. However formidable the job, the aim is always to avoid occupying normal productive time whether the time available be a normal weekend mill shutdown, a holiday fortnight, or the time required for a blast-furnace reline. The habit of mind so developed does apply itself to the smaller jobs and to those unheralded cases of accidental damage which are experienced from time to time.

Time and job schedules are put into graphical form as bar charts wherever necessary on a day-by-day, shift-by-shift, or if necessary on an hour-by-hour basis. Examples of such charts are shown in the papers already referred to.[2, 3]

EXAMPLES OF MAINTENANCE WORK

Slab Shear

After 28 years' service, extensive corrosion of the machined faces of the housings and broken foundations of this 54 in. × 18 in. hydraulically operated shear forced the decision that the machine must be completely stripped, the housing standards, each weighing 26 tons, remachined, the foundations made good, and a heavy sole plate placed under the housings. This was necessary, particularly in the face of growing outputs and the establishment of a forward programme of general rehabilitation for the slabbing mill auxiliaries.

Consideration of this job started from the conviction that it could not be achieved within the mill holiday fortnight. The machining of the housings was beyond the capacity of the Company's own shops and one of the first problems was to settle whether to have these housings machined or to fabricate new ones. Although the shear-maker's holiday period coincided with the time the work would require to be done, arrangements were concluded for the appropriate machine crews to be on duty for this work, special road transport was organized and one of the Company's assistant engineers was detailed to remain at the shear-maker's works for the whole of the time the machining was in progress in order to effect the fullest possible liaison between the two parties. At the same time Meehanite type WA window liners were to be fitted.

The sole plate, rolled from a 20-ton ingot, called for special arrangements between engineers, design office, production departments, and central engineering workshops. The ingoing and outgoing roller tables had to be moved out of the way. The full extent of the damage to foundations could not be determined until the housings were removed.

Nevertheless, discussion went on and a work schedule, confined to the holiday fortnight, was gradually built up. This schedule involved some 6500 man hours of site work on three-shift working by fitters, pipefitters, riggers, and civil engineering labour, apart from the machining work carried out by the manufacturer.

With the help of an appropriate incentive payment method the work was in fact accomplished in the mill holiday fortnight and has amply justified the time and trouble involved.

6000-h.p. (R.M.S.) Mill Motor

This motor, driving the 10-ft. plate mill, developed a series of breakages in the end windings of the driving end armature in 1946 and 1947. Metallurgical examination revealed crystallization of the copper and further failures were therefore imminent. First enquiries resulted in a time of some eight weeks being required for rewinding the one armature and 3–3½ years for the manufacture of a complete new double armature. New windings were ordered and examination of rewinding time commenced in earnest. In discussions with the maker and later, in addition, with a repair company the time was brought down fairly quickly to 4 weeks. The objective was, however, to get the work done within the holiday fortnight and discussions continued to within a few weeks of the commencement of the job devising means of quickly stripping out the old winding, staging for most comfortable working positions, and layout and arrangement for minimum fatigue of the winders. The outcome was that it was agreed the work could be done within the 17 days of the holiday shutdown subject to there being no difficulty with the fit of the coils, etc.

In fact, using 8 winders and their assistants working two 12-hr. shifts per day, the winding work was completed on the thirteenth day after the shut-down, in spite of an unforeseen difficulty with the new equalizer rings, and the reassembly of the motor was completed with ample time to spare before the mill was due to restart.

Subsequently, with the experience gained a similar rewind on an identical motor driving the slabbing mill was completed on the eleventh day after the shutdown and the motor was reassembled and tested on the twelfth day. The first time is always the hardest !

An example of the kind of bold action it is sometimes necessary to take also concerns the 10-ft. mill motor. It was necessary to lift the armature, weighing 102 tons, in order to replace defective field windings. The crane capacity was only 60 tons. A structural steel gantry was fabricated and erected spanning the motor bedplate and provided with two travelling trollies with suspension rods. The suspension rods were provided with hand nuts at their upper ends. The armature was lifted step by step one end at a time by the overhead crane and the suspension rod nuts were taken up until the armature was lifted to the extent of half its diameter. It was then traversed over towards one side of the motor, and the repairs were completed and the motor reassembled well within the holiday shutdown.

5000-h.p. (R.M.S.) Mill Motor

This motor drives the three-stand 32-in. section mill and although the example relates to the reconstruction of the Frodingham section mills it is felt to be one which well illustrates the principles of organization which must be and are applied in maintenance work. The motor was to be erected temporarily at the first roughing end of the mill on its then alignment and later moved to its permanent position. It was known that the move to the final position would have to be carried out against a strict time limitation—it was thought that 3 weeks might be available. The contracting company would not commit itself to less than 8 weeks.

By exercising close supervision on the initial erection to reduce waiting time for crane lifts and to ensure that parts and tools were to hand as required, the motor was given its first test run 23 days after commencement of erection of the bedplate, and was ready for productive service 4 weeks and 4 days after commencement in spite of an unforeseen setback due to an error in foundation level. Careful observations of operation times and factors affecting these operations were taken throughout the erection.

Continued study of the operations on mills and auxiliaries which would have to go on simultaneously with the transfer of the motor to its final position revealed the possibility of achieving this work within the mill holiday fortnight. The motor would therefore have to be moved in this time if it were not to become the limiting factor.

Examination of the observations taken during the first erection of the motor showed that transfer in two weeks was not likely to be achieved unless a second bedplate was obtained and was lined and levelled prior to the commencement of the holiday fortnight. This was done.

A time and job schedule on an hour-by-hour basis was drawn up for the dismantling of the motor and intensive supervision exercised on the principle that a job must be started in the manner in which it is to go on throughout its progress. The motor was stripped down to its bedplate in 6¼ hr. from the mill stopping work.

The time and job schedule for re-erection was prepared on a day-by-day basis making the fullest use of the data collected during the initial erection. The 66-ton armature was placed in its bearings in the permanent position less than 48 hr. after the mill shutdown, the first trial run was given on the 12th day after the shutdown, and was complete and ready for production by noon on the 15th day after shutdown with 34 hr. to spare before the mill was due to restart.

32-in. Mill Changeover

This example again relates to the reconstruction of the Frodingham section mills at the same stage as the preceding example and is also chosen to illustrate principles of organization. During the week preceding the holiday fortnight the mill was to roll only in the first and second roughing stands in order to enable the existing finishing mill housings, manipulators, and part of the front and back roller tables to be dismantled and the new finishing mill housings and new parts of the front and back roller tables to be erected in their new position further to the front side of the original positions. During the holiday fortnight the first and second roughing housings, together with the back second roughing roller tables, were to be moved to their new locations; roller tables, spindle balance gear, etc., to be dismantled; finishing mill pinions and front side manipulators, spindle balance gear, pipe bridge, remainder of back roller tables and new parts of run-out table to saws to be erected.

The work was broken down into 15 major units and each detailed, described, and docketed with its appropriate set of drawings. The men who were to do the work—the Company's own employees in this case—were addressed on several occasions, taking them through the programme step by step with the aid of a layout plan and cut-out models, and through each job analysis, and the work was freely discussed. Also, each man was given a personal copy of the description of the parts of the work on which he would be engaged. In this way interest was built up and sustained and a team spirit engendered without which such a formidable programme certainly could not have been achieved. The work was completed within the time allotted.

In each of the foregoing examples there is the common factor of painstaking prior planning. The references to time and job schedules are brief, but for any major job such a schedule involves discussion and argument among staff of long experience often for months before the final timing is agreed. Even so, as anyone with maintenance experience knows, there are frequently operations involved which for a variety of reasons cannot be timed accurately in advance and it is only by experience—generally collective experience—that realistic programmes can be built up.

In the event, there are operations which go better or worse than expected. Advantages gained must be pressed home and any adjustments to timing made quickly on the spot. Difficulties encountered must be the subject of speedy and perhaps bold decisions. The overall result reflects the quality of the supervision.

INSPECTION

It is proposed under this heading to discuss plant inspection in general terms as carried out at Appleby-Frodingham and to examine in more detail two cases which might be described as experiments in methods of planned maintenance. The worth of one of these methods, it is submitted, can be evaluated, and although it has not been possible so to evaluate the other it is submitted that its necessity can be demonstrated.

Inspection is the basis of any methodical maintenance—indeed, the prevention of breakdown or other cause of delay is surely implicit in the word maintenance. Shortly before the late war it was felt necessary to try to rationalize inspection and the recording of inspections. The plant inventory department was to operate the clerical aspects of the work in issuing inspection forms at intervals determined by the plant engineers and the recording of findings and the action taken. The actual inspections were to be carried out by the departmental personnel. As may be imagined there were difficulties arising from suspicion of new methods and the feeling that responsibilities were being interfered with, and before the initial difficulties could be satisfactorily overcome the late war had begun, bringing with it a number of new problems, not least of which was shortage of manpower.

The system consequently fell largely into disuse but was gradually developed for electrical plant inspections and is established as the accepted method for this class of work. It must be stated, however, that especially in the case of mill and crane contactor gear where satisfactory operation is dependent on a large number of small working parts this system in no way takes the place of the day-to-day conscientious observation of the individual maintenance electrician.

The system has also been established for the inspection of ' semi-domestic ' buildings and for the inspection of cladding, guttering, fall pipes, and walkways of structural steelwork industrial buildings.

The maintenance procedures for ironworks and coke-oven plant generally are very largely conditioned by the fact that most of the equipment is in continuous operation and planned work is accumulated to be carried out on stop days in the case of ore-preparation plants, during furnace relines, or otherwise by specially arranged stoppages. The plant engineer's staff who have responsibility for specific sections of plant carry out inspections and record any necessary maintenance work. Also the plant attendants record on their log sheets any irregularities they may observe. Log sheets and recorder charts are examined for the evidence they yield of the necessity for routine maintenance or of incipient trouble. Structural inspections, with special emphasis on furnace structure, stoves, and gasholders, are carried out by a specialist full-time inspector responsible to the plant engineers. The method works well but it is considered desirable to effect a greater measure of rationalization of regularity of inspections and recording of observations, and a localized office of the plant inventory department, from which the clerical aspects will be dealt with, is being organized.

In the two steelworks it was considered necessary shortly after the end of the war, because of the need for rapidly increased outputs and because of the difficulties and deterioration brought about by war conditions, to make a systematic attack on the level of delays. Accordingly, an assistant engineer for inspection was appointed to each of the steelworks, responsible to the respective plant mechanical engineers, with a small number of full-time craftsman inspectors to institute a system of inspection and planned maintenance. This amounts to a special development of the original system with all the records and the clerical work localized in the plant engineer's office. It is proposed to discuss the case at Appleby Steelworks later.

Throughout the foregoing it will be noted that inspection work is held to be the responsibility of the plant engineer irrespective of how the clerical work is done. The policy has been developed from the concept that this is essentially an important aspect of the work of the plant engineer and that he should be responsible both for inspections and the consequent actions to be taken. In this way conflict of interests is substantially avoided and any which might arise can be settled quickly on the spot by the plant engineer.

An exception to the general rule is the special case of the statutory inspections of boilers and other pressure vessels and cranes which are carried out by an engineering insurance organization—the widely used practice in this country in order to satisfy the ' competent person ' requirements of the Factories Acts. These statutory inspections most certainly do not relieve the plant engineer of making more frequent inspections. Some years ago arrangements were made with the insurance company to group the inspections of overhead cranes for each works. Thus the plant engineer can plan a bulk operation with the user departments, thus achieving less overall dislocation of productive processes than with these inspections spread throughout the year.

INSPECTION SYSTEM AT APPLEBY STEELWORKS

It is now proposed to discuss the general organization and method of operation of the system instituted at Appleby Steelworks and to quote data which, it is submitted, amply justify the setting up of the organization. This section is chosen because most of the primary equipment has been in operation nearly 30 years and, as is to be expected, quantitative results can be shown in a way which would not be possible on new plant.

It is not necessary here to detail the objectives except to state that one of them was to keep the paper work to a minimum.

The personnel consists of:

Assistant engineer (inspection)
Junior assistant engineer (inspection)
2 clerks
1 typist
6 inspectors
4 for general plant
1 for overhead cranes
1 for wire ropes.

The foregoing are accommodated in three offices of areas 165, 165, and 179 sq. ft.

These full-time inspectors are picked men who, apart from craft skill and experience qualifications, are capable of writing down their findings clearly and concisely. This last is by no means an easy part of the requirements to satisfy and is an insuperable difficulty to some of the older and most experienced craftsmen who would otherwise be first-class inspectors. The inspectors are not on the staff and it is believed this is a material factor in the acceptance of the system by the men generally. They are paid a little above the standard rates.

The procedure is based on two kinds of inspection:

(1) *Plant Working* (*known as ' Daily Running Inspections '*)—The whole of the mill equipment from the approach roller table for the slabbing mill right through to the plate-shearing and loading equipment is inspected each day whilst the plant is in operation. The equipment in the Appleby melting shop, pig-casting plant, basic slag plant, and the overhead cranes is inspected at lesser frequencies determined by the inspection engineer and governed by the nature of the plant and the service conditions. It is in these inspections that the skill of the inspector is perhaps most highly tested in interpreting the external visual and aural signs of internal conditions.

(2) *Plant at Rest and Opened Out* (*known as ' Period Inspections '*)—All the plant has such an inspection generally not less frequently than each 16 weeks but, where necessitated by the nature of the plant and service conditions, at various frequencies up to as often as every month.

Daily Running Inspections

The mill equipment is divided into nine clearly defined areas for each of which a card is printed detailing the items of plant in the area and the principal components of each. The inspectors fill in each card every day the plant is working with their observations of matters requiring attention.

These cards are examined by the inspection engineer the same day, points discussed with section assistant engineers or the plant engineer if necessary, job cards made out as necessary, and these jobs entered in a ledger which provides the permanent record. The job cards are then issued to the general foreman for issue to the appropriate shift or day foreman who will see the work carried out. On return in due course with a concise description of what work was in fact carried out and endorsed by the general foreman, the entry in the ledger is completed and after an interval the job cards and the inspection report cards destroyed. It is difficult to envisage a reliable system which would involve less paper in circulation or finally retained.

Should an inspector discover a condition requiring immediate attention to forestall a breakdown he tells the nearest appropriate maintenance man and the shift foreman. He then informs the inspection engineer who immediately issues an emergency job card to the general foreman and tells the section assistant engineer. All parties involved are thus informed quickly so that the most appropriate action may be taken.

The equipment for the Appleby melting shop, pig-casting plant, and basic slag plant is dealt with similarly, with running inspections daily or twice weekly as necessary and in a few instances weekly.

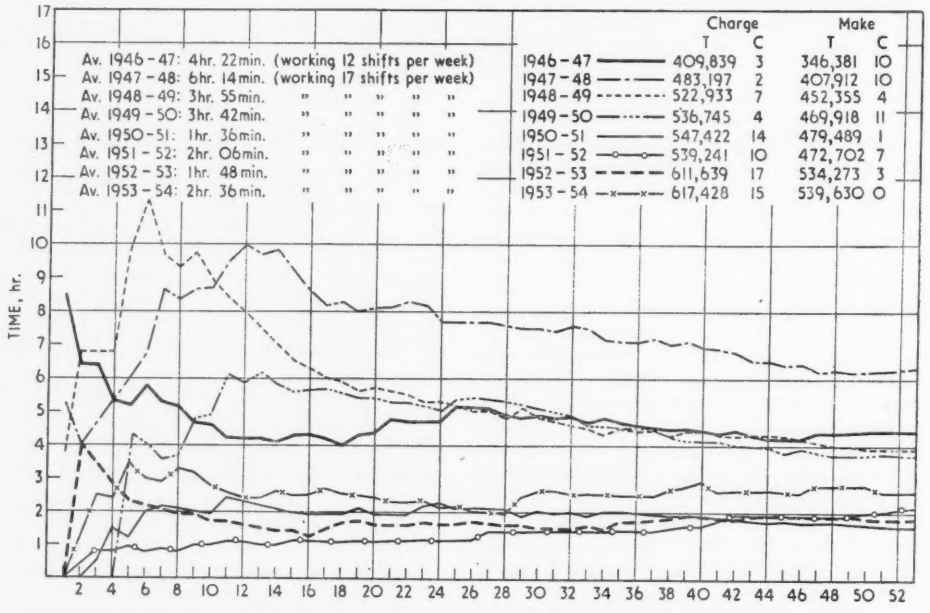

Fig. 2—Cumulative weekly average mechanical delays in the slabbing mill from stop period to stop period

Overhead cranes constitute a special case since there are 55 of them distributed over a large area and it is considered neither feasible nor necessary to carry out a running inspection on each one every day. The inspection rota is arranged so that certain cranes—particularly hot-metal cranes—are inspected each day and all the cranes and chargers receive a running inspection in a fortnight. The inspection schedule must of course be very much more flexible than in the case of ground inspections in order to avoid interference with production.

Period Inspections

Inspections with the plant at rest and covers removed are necessarily confined in the main to weekends in respect of rolling mill equipment. They are, however, carried out during the week as time allows during meal breaks or standing time from any other cause.

From a key planning chart the inspection engineer prepares each week a list of period inspections, and, subject to confirmation by the Plant Engineer that the items will be available for inspection, it is put into effect. The report sheets used detail the items of plant more fully than in the case of the daily sheets. Opening out and reassembly is done by the inspectors with the assistance of mates and if extra help is needed this is readily given by the maintenance personnel. The wear observations taken during these inspections are of value in checking, and if necessary adjusting, the estimated life of wearing parts on which the accountancy of maintenance provisions depends. The job card technique is the same as for running inspections.

For convenience of identification the job cards are colour-coded—white for those resulting from daily running inspections, yellow for emergency jobs, and blue for those resulting from period inspections.

Cranes period inspections are organized by the issue of weekly lists covering 4 or 5 cranes and the cranes assistant engineer or cranes foreman arranges with the production personnel for the availability of the cranes for inspection and with other maintenance functions to make full use of the stoppages. Conversely, if a crane stoppage has to be arranged for repairs or replacements the opportunity is taken to carry out a period inspection.

Rope Inspection

The ropes inspector spends his full time on this work and his most important function is clearly in connection with crane ropes, but he also covers all other wire ropes, e.g. furnace door ropes and mill skid ropes. In addition to routine inspections he also carries out special inspections of ropes reported or known to have been subjected to abnormal conditions. The inspection observations are charted and card-indexed so that the state of ropes is kept constantly before the cranes assistant engineer or whoever else of the assistant engineers may be concerned. Job cards are not issued for ropes and renewal decisions are taken as necessary, although as many ropes as practicable are put on a predetermined routine renewal basis.

Checking

Each week a summary is prepared for the plant engineer showing the numbers of job cards issued and returned in the week, and in the inspection year to date, together with the numbers outstanding. This summary separately shows the position of daily and

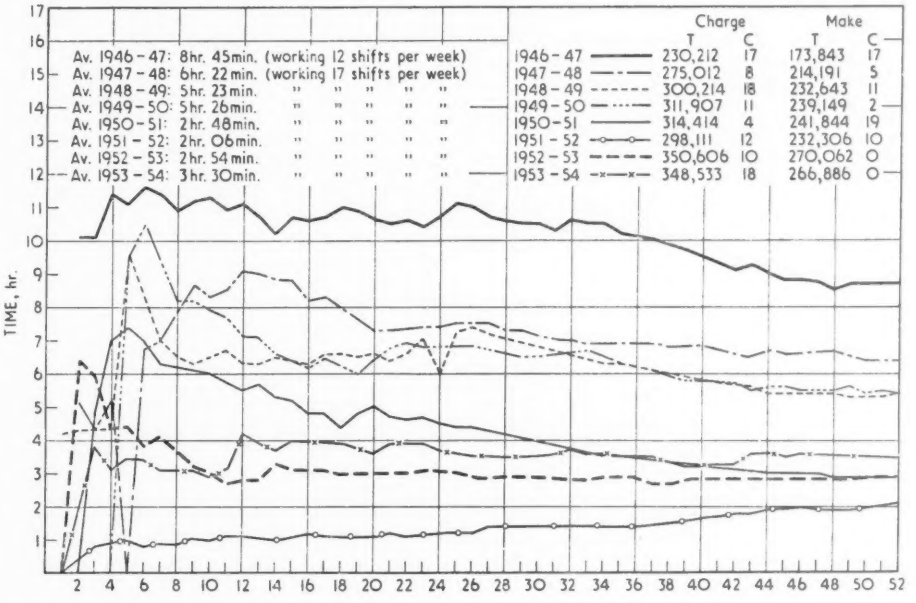

Fig. 3—Cumulative weekly average mechanical delays in the 10-ft. mill from stop period to stop period

period inspection job cards for each section of the plant including cranes. The summary also includes a more detailed list of outstanding period inspection job cards, and the leading observations on the inspections in the melting shop, pig caster, etc.

The plant engineer is thus enabled to take whatever action may be necessary in respect of outstanding work.

Effectiveness and Value

The extent to which emergency cards need to be issued may be regarded as an indication of the standard of maintenance achieved and since the number of emergency cards issued for the mills has progressively fallen from 110 in 1949–50 to 13 in 1953–54, and for cranes from 26 in 1950–51 to zero in 1953–54, it would certainly seem reasonable to deduce that the inspection and job card system has been effective in bringing about an improved standard of maintenance of the plant.

It may be of interest to note that in 1953–54 a total of 4240 job cards were issued, 2553 for the mills and 1687 for cranes, and that these cards include on average two jobs to be carried out.

More striking are the graphs (*see* Figs. 2, 3, and 4) showing the cumulative weekly average mechanical delays in the slabbing mill and the 10-ft. and 7-ft. plate mills over the past eight years from stop period to stop period, and the marked reduction which has been achieved in spite of generally increasing levels of output and without any significant variation in the maintenance manning throughout these eight years. The number of workmen engaged on maintenance functions, excluding plant attendants, has varied little from 390. This number covers fitters, pipefitters, riggers, greasers, handymen, and labourers.

It is of interest to note a slight tendency to an increasing level of delays and this is believed to indicate that at least some of the plant has reached or passed the optimum age for present output levels and that only major replacements and rebuilds can turn this trend. This view is supported by knowledge of the plant and in fact an extensive rehabilitation programme has been formulated and has partially taken effect in the 7-ft. mill.

It is also considered that the observations of the foregoing paragraph can be taken to indicate that the level of inspection activity is about right.

Whilst it would be unrealistic to relate reductions in delays to increased tonnages at normal rolling rates it would be reasonable to claim that certainly some of the increased level of annual outputs is attributable to reduced delays, and quite a small proportion of the increased tonnages allocated to reduced mechanical delays amply justifies the cost of the personnel for the inspection system and the capital investment of their modest office accommodation.

ELECTRICAL TEST SECTION

It is now proposed to discuss a case for which it is difficult to find a basis for evaluating its worth but which is nevertheless necessary.

Although the need had been recognized for many years for a regular routine it was not until 1951 that it was possible to allocate an assistant electrical engineer to organize the testing and maintenance of electrical protective systems, energy meters, and indicating instruments, and the regular testing of transformer oil and earth electrodes. The section was also to deal with special measurements and investigations, and cable fault location.

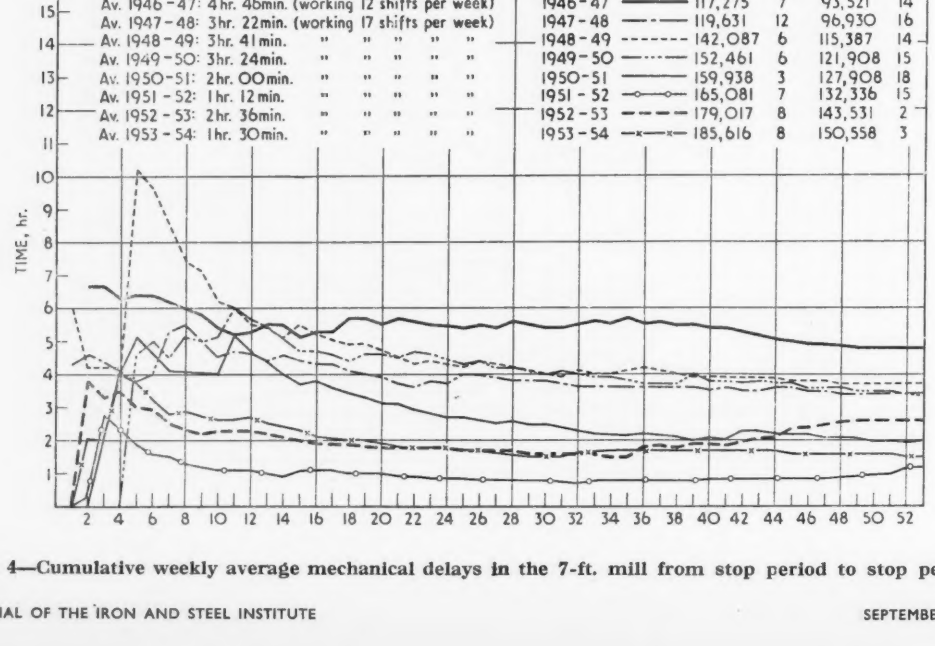

Fig. 4—Cumulative weekly average mechanical delays in the 7-ft. mill from stop period to stop period

It had been the practice for many years to check generator energy meters from time to time against a substandard instrument and, following an established failure of a Merz-Price protective equipment, sporadic tests had been carried out on other similar equipments. In general, however, very much was taken for granted and earth electrodes virtually completely so. No doubt many engineers would be prepared to admit that these conditions were not unusual.

At the time the section was set up the use of electricity was at the rate of over 200 million units per annum and is now at the rate of 350 million units per annum. This energy is allocated weekly to the user departments for costing purposes on the basis of the readings of over 300 switchboard energy meters apart from subcircuit meters. The money value involved is substantial and presumably no one would deny that the meters should be kept within reasonable limits of accuracy. Only testing can enable this to be achieved and only an organized system with appropriate records can ensure any measure of control. Anything less will fall into desuetude. In fact approximately 75% of the meters in service for 25 years were found to have serious errors and, indeed, about half of these were beyond repair because replacement parts were no longer available. Approximately 50% of the more recent meters had errors upwards of 1·5% and about 6% were in need of major repairs.

Protective systems are expensive and are installed to limit the extent of any fault damage in even more expensive equipment or to prevent the effects of a fault spreading further afield than necessary, and, of course, to limit any interruptions of productive processes. They may remain unoperated for years and it must be worth incurring some expenditure to ensure that they will function as intended should the occasion arise. There are over 250 protective systems installed on the Company's power system—including all induction relay over-current and earth-fault protection—and the results of tests since the setting up of the test section have certainly proved that these may not be taken for granted. This was in fact forcefully demonstrated some years earlier when a 4500-kVA. gas-engine driven alternator with a stator internal diameter of 28 ft. developed a fault at top dead centre and failed to clear on the protective gear. The fault was sustained long enough for fire to be carried round the whole of the stator end-windings by the windage, necessitating a complete rewind, and the core in the vicinity of the fault was very severely damaged by arcing, necessitating a rebuild of the core. The cost of the repair was nearly £4000 (equivalent to £8000 now) and the machine was out of action for 6 months with a loss of 11½ million units of electricity from process fuel.

Investigation into the failure of the Merz–Price protective gear to function revealed serious defects in current transformers. Had the protective gear functioned as it should have done it is unlikely that any serious core damage would have occurred and that winding repairs could have been effected well within a week using the few spare coils held in stock.

There are over 100 power system and lightning conductor earth electrodes on the plant, which are now tested and recorded. Within a short time of starting this work a defect in a main power system earth electrode was found and on excavation it was found that the connection had corroded away within 13 years of installation. This condition certainly needed to be revealed for safety, for the satisfactory operation of protective gear, and not least, to comply with the law. Of 32 chimney lightning conductor earth electrodes only 8 were found to be within the value of 10 Ω recommended by the B.S. Code of Practice. Of the remainder 15 were double and 9 more than double the recommended value, the highest being 65, 70, and 200 Ω. Even if it were argued that the B.S.C.P. figure is somewhat arbitrary it would be difficult to defend values in excess of double and even as high as 20 times the B.S.C.P. figure in the event of serious lightning damage to a chimney.

Some transformers have had to be scrapped owing to deterioration brought about by high acidity of the oil. The test section carries out regular oil tests on all transformers operating at 2500 V. and over and the results have enabled appropriate action to be taken where neutralization values in particular were dangerously high.

In addition, the section carries out a host of special tasks, e.g. precision power and oscillographic measurements for special investigations, duty cycle investigations, cable fault location, power factor investigations, initial lighting installation test sheets, fault energy calculations, etc.

The personnel consists of:

Assistant electrical engineer
Technical assistant
Two electricians
Two apprentices.

The apprentices who have served with the section as part of their training have so far been those who are doing well academically. The amount of special investigation work has increased beyond expectations and at least two more men are needed.

The work is necessary and valuable and the personnel and equipment involved in relation to the value of the electrical energy used, the value of the electrical plant, or the total electrical maintenance manning for the works is indeed modest. It would appear not to be possible to find any method of quantitative evaluation of the worth of this activity, particularly in relation to output of products and that the intensity at which it should be pursued can be determined in no other way than by experienced judgment.

LUBRICATION

Lubrication is an important aspect of maintenance activities which involves substantial costs and some years ago it appeared this would be a fruitful field in which economies and improvements might be effected. Indeed specialist lubrication engineers were already established in the U.S. metal industries. Accordingly, in 1948 in common with other branches of the United Steel Companies a specialist lubrication engineer was selected from the existing staff and given a period of training with one of the major oil companies.

He works in close collaboration with the plant engineers and their assistants, and with the purchasing

and stores departments, and supervises the implementation of lubrication policy which he assists in formulating through his membership of a sub-committee composed of the lubrication engineers of the United Steel Companies group. He in no way cuts across the executive responsibility of the plant engineers and their lubrication foremen for the work of greasers, lubrication equipment attendants, and the fitters who install and maintain lubrication equipment.

He is, however, responsible for selecting and scheduling the lubricants to be used throughout the works, advises as to their methods of application, investigates all problems arising from their use, and is responsible for the economic re-use of lubricants removed from circulatory systems when no longer fit for their original purpose. In conjunction with his colleagues from the other branches he draws up the control specifications in pursuance of a standards policy and he interprets the results of any laboratory or site test routine which is made. He consults with the design department and as far as possible with outside suppliers as to the provisions to be made for the lubrication of new or projected items of plant and examines the claims made for new products, appliances, and techniques.

The fundamentals on which the lubrication policy is based can be briefly stated as follows:

(*a*) Lubrication is an engineering function and as such is undertaken by engineering personnel

(*b*) Manual methods are subject to chance, wasteful of time and materials, and often dangerous so that the fullest possible use is made of mechanical devices

(*c*) Wherever possible, plant is designed or adapted for lubricant circulation, but where total-loss lubrication must be accepted, devices which relate the quantity fed to the work done are employed so far as is practicable

(*d*) Contaminated lubricants defeat their own ends, consequently methods of storing, dispensing, and applying them are devised to ensure maximum cleanliness at every stage

(*e*) Complicated schedules increase the likelihood of misapplication and are not conducive to good housekeeping. Whilst each lubricant employed must be adequate for the purpose intended, every effort is made to keep the number of grades to a minimum.

The gains which have resulted from the application of this policy cannot be accurately assessed for the works as a whole, mainly because of the changes brought about by extensions, reconstructions, and redundancies which are continually taking place, but some tendencies may be gathered from the following points:

(1) At the Frodingham blooming and section mills, where there has been no substantial modification or addition since 1949, delays attributable to lubrication average about 15 min. per 10,000 possible working hours or less than 10 min. per year.

(2) Since the installation of a grease service station at the Appleby melting shop piped to crane track levels, the consumption of grease has fallen by more than 400 lb. per week and the average time taken to service a crane or charger from about 30 min. to 5 min. This shop is 440 yd. long.

(3) The number of different grades of oils and greases used in 1948 was 90 as compared with 31 at the present time. This number could be still further reduced but for the fact that it is uneconomical to use the higher priced multi-purpose lubricants on some of the older items of plant. This telescoping of grades has enabled a programme of bulk storage and delivery to be put in hand with its attendant advantage of reduced risk of contamination, closer control of quality and consumption, and not inconsiderable saving in space and cost.

It is not out of place here to mention that the arrangement outlined above went into effect very smoothly in respect of personnel relationships. This is no doubt a tribute to the tact and the impartiality of the individual concerned and the fact that he was already a well established member of the staff.

EVALUATION OF MAINTENANCE WORK

It is by no means easy to find a satisfactory basis for measuring the effectiveness of maintenance work but it is nevertheless necessary to find some aspects which can be removed from the realm of opinion.

Each day the plant engineers submit reports on production time lost owing to engineering causes, together with brief statements of the reasons and the action taken, and their reports are transmitted to top level management.

Each week the production time lost for units of plant, e.g. slabbing mill, is tabulated by the cost office into the component causes—heat (steel or gas), roll changing, mechanical, electrical, etc.—and against each cause and in total the delays for the week, the cumulative average for the financial year to date, the average for the previous financial year and the ' works value ' are stated.

Similarly, each week the maintenance costs for works—e.g. Appleby mills—are tabulated into the main components of the works, and against each item and in total the cost for the week, the cumulative average for the financial year to date and the average for the previous financial year are stated. Additionally, the costs for the week are broken down into plant item numbers with departmental classification of costs, and renewable items which have differed materially from forecast life are brought out separately together with the financial gain or loss involved. This matter of plant lifing is a very important factor in accurate budgeting of financial provisions for maintenance.

These weekly tabulations of delays and costs enable all those concerned to keep a check on—and explain if and as necessary—performance in relation to total working time (availability) and output, and, especially important, to keep under constant review the general trends.

Each four weeks departmental overhead costs are tabulated along with the corresponding ' works values,' circulated, and scrutinized. Although there are items in such a build-up of costs which the individual engineer cannot control, e.g. National Insurance and holidays with pay allowances, there is much that he can directly control or at least influence favourably.

Strength of manning is dealt with by standards in departmental and sub-departmental divisions and manning is not allowed to go beyond these standards without special reason. Further, any request for an increase of standard must be fully supported and

argued and conditions which might justify a reduction of standards are followed up.

Each year the cost of separate maintenance functions divided into materials and labour is extracted for major production activities, summarized on a cost per ton basis, and compared with preceding years after making appropriate adjustments for changing price levels.

Also, each year the overall maintenance manning, man-hours, finished outputs, and maintenance man-hours per ton are extracted, and also the man-hours for each separate maintenance function and the figures compared with preceding years.

It could not be claimed that any or all of the above factors enable a quantitative decision on level of maintenance work to be made, although the effect over a suitably long period of controlled increase or decrease in maintenance expenditure could be examined. On the other hand these checks do enable the cost and effect of maintenance to be kept within the established bounds in pursuance of the general policy of, within reasonable limits, keeping the plant 'as new' and top-level management is enabled to take a decision, should the need arise, whether to vary the levels of maintenance expenditure with reasonable knowledge of what the consequences might be.

SPARES STOCKS

The amount of capital locked up in spares can and does reach magnitudes which must of necessity give top-level management cause for serious concern and if ever there were a repetition of the 1920 slump, the effects of which were recently referred to by Sir Charles Bruce-Gardner,[5] the losses sustained would be most serious. It is certainly the responsibility of every maintenance engineer to satisfy himself that he is not calling for spares held in stock in excess of levels dependent on all the circumstances prevailing from time to time and it is proposed here to state a problem for discussion rather than to postulate any real measure of overall control.

Clearly the level of spares stock investment must depend to a very large extent on the level of production delays which can be regarded as acceptable and what repair facilities are immediately available. It must also be considerably influenced by the particularly long delivery times which have prevailed in post-war years. Even with stable conditions, however, it is extremely difficult to find any actuarial basis on which to determine what optimum insurance premium in spare stocks should be paid to ensure satisfactory availability of the plant.

Examinations have been made relating actual spares stock values in total and section by section to original plant value, to replacement plant value, and to weekly or monthly usage of spares, but no indication of a generality of level emerges from such investigations.

The adoption of a policy of standard specifications and dimensions does help towards limitation of spares but so much of heavy plant is of the one-off kind which, at the time it is installed or ultimately replaced, incorporates the then current best practice. In the case of some components, e.g. ball and roller bearings, control can be and is exercised through the stores organization to see that stocks are not unnecessarily duplicated and, in the case of wearing parts, the control of lifing does enable a close determination of spares stocks to be made in relation to delivery times. It remains difficult to determine where the dividing line ought to come between, say, a decision not to carry spare main mill pinions and a decision to carry a complete reduction gearbox for a conveyor belt.

At a time of high demand when high plant availability is especially valuable the optimum economic spares stocks provision is probably that required for almost excessively frequent renewals of wearing parts and almost excessive anticipation of possible breakdowns. In this condition there certainly lies the risk of the development of habitual over-provision of spares but unless or until some basis is found for determining the optimum for any set of circumstances it would appear that the reasonable limitation of provisions must depend fundamentally on the conscientious appreciation of the problem by each individual engineer, subject to such overall direction as higher management may deem necessary to make from time to time.

CONCLUSION

It has been necessary to omit much which has a bearing on maintenance organization—not least recruitment, education, and training of apprentices, foremen, and engineers—in order to avoid an excessively long paper. In general the paper has been confined to what has been or is being done in what is believed to be a successful organization and the author has tried to avoid theorizing on the activities of a maintenance organization. A fuller treatment of some of the subjects mentioned in the paper will be found in the special issue of *Iron and Coal Trades Review*, to be published early in September, 1955.

It is hoped the paper may provide a number of well defined points to stimulate a discussion based on the realities of experience on the occasion of the special meeting in Scunthorpe.

Acknowledgments

The author is grateful to the Appleby-Frodingham Steel Company for permission to publish this paper and to his colleagues who have assisted in its preparation.

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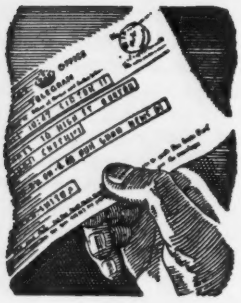

N E W S

Announcements and News of Science and Industry

THE IRON AND STEEL INSTITUTE

Special Meeting in Scunthorpe, 1955

As previously announced, the Council of The Iron and Steel Institute have accepted an invitation from the Lincolnshire Iron and Steel Institute to hold a Special Meeting in Scunthorpe, from **Wednesday, 12th October, to Friday, 14th October, 1955.** A Reception Committee has been formed in Scunthorpe under the Chairmanship of Lieut.-Comdr. G. W. Wells, R.N.(Ret.), D.L., President of the Lincolnshire Iron and Steel Institute; a Ladies' Committee has also been formed, and Mrs. G. W. Wells has kindly consented to act as Chairman.

The following is the programme:

Tuesday, 11th October

Members and Ladies arrive in the Scunthorpe area.

Wednesday, 12th October

Morning: Opening Session at the Drill Hall, Beck Road, Scunthorpe, followed by the presentation and discussion of the following papers:

"*Developments in Ironmaking at Appleby-Frodingham*," by G. D. Elliot

"*The Expansion Scheme at John Lysaght's Scunthorpe Works Ltd.*," by W. L. James.

Afternoon: Visits to works and ore mines with lunch and tea by invitation of the Companies visited (*see* below).

An all-day visit to Lincoln with lunch and tea will be arranged for the Ladies.

Evening: Reception and Buffet Supper at the Baths Hall, Scunthorpe, by invitation of the Mayor and Corporation of Scunthorpe.

Thursday, 13th October

Morning: There will be two simultaneous technical sessions for the presentation and discussion of the following papers:

(Session *A*—in the St. Lawrence Church Hall, Scunthorpe)

"*Steelmaking at Redbourn*," by S. R. Isaac

"*Organization for Maintenance*," by J. L. Gaskell.

(Session *B*—In the Lecture Theatre, North Lindsey Technical College, Scunthorpe)

"*Underground Mining of the Frodingham Ironstone Bed at the Dragonby Mine, Scunthorpe*," by C. Smith

"*Development of Chemical Methods for the Treatment of Low-Grade Ores at Appleby-Frodingham*," by L. Reeve.

Afternoon: Visits to works and ore mines with lunch and tea by invitation of the Companies visited (*see* below).

Ladies will visit the Old Hall, Gainsborough, for lunch, and Normanby Hall (by kind permission of Lt.-Col. E. C. R. Sheffield, D.L., J.P.) for tea.

Evening: Dinner and Dance by invitation of the Lincolnshire Iron and Steel Institute at Elsham Hall (by kind permission of Capt. J. Elwes).

Friday, 14th October

Morning (Members and Ladies): Visits to works and ore mines (*see* below).

Technical Sessions

The papers to be presented at the Technical Sessions on Wednesday and Thursday, 12th and 13th October, are published in this issue of the *Journal*, with the exception of that by C. Smith, which is to be published in the October issue.

Visits to Works and Ore Mines

The following works visits will be available to Members on the afternoons of Wednesday, 12th, and Thursday, 13th October, and to Members and Ladies on the morning of Friday, 14th October:

(i) Appleby-Frodingham Steel Co. ('Seraphim,' blast-furnaces, sinter plant, ore-preparation plant)

(ii) Appleby-Frodingham Steel Co. (open-hearth steel-plants, plate mills, section mills)

(iii) John Lysaght's Scunthorpe Works Ltd. (blast-furnaces, open-hearth steelplant, rolling mills for billets, rods, and sheet bar)

(iv) Richard Thomas and Baldwins Ltd., Redbourn Works (blast-furnaces, open-hearth steelplant, rolling mills for billet and sheet bar)

(v) Thos. Firth and John Brown Ltd. (steel foundry)

(vi) The United Steel Companies, Ltd., Dragonby Ironstone Mine.

Eighth Hatfield Memorial Lecture

At the invitation of the Council of the University of Sheffield, Dr. E. C. Bain, Vice-President, Research and Technology, United States Steel Corporation, has agreed to deliver the Eighth Hatfield Memorial Lecture.

The subject of the Lecture will be "*Trends in Metallurgical Research in the United States*," and it will be given at 6.30 P.M. on **Monday, 17th October, 1955,** in the Firth Hall of Sheffield University.

The Council of the University extends a cordial invitation to all members of The Iron and Steel Institute to attend the Lecture. Admission will be by ticket only, and applications should be made to the Registrar, The University, Sheffield, 10, without delay. (See separate insert in this issue).

Autumn General Meeting, 1955

The **Autumn General Meeting** of The Iron and Steel Institute will be held on **Wednesday and Thursday, 16th and 17th November, 1955.** Full details of the programme will be given in a later issue of the *Journal*.

NEWS OF MEMBERS

▶ Mr. M. D. J. Brisby has left B.I.S.R.A. to take up an appointment with the Iron and Steel Board.

▶ Mr. E. C. Brough has completed his training at Huddersfield Training College, and has joined the teaching staff of Luton Technical College.

▶ Mr. F. W. R. Banks has been appointed Chairman of the newly-formed Johnsons Rolls Ltd., and Mr. C. Rowley and Mr. K. H. Wright have been appointed Directors.

▶ Mr. A. D. Busby has left the Development and Research Department of The Mond Nickel Co., Ltd., to become Deputy Process Development Manager of the Titanium Department, Metals Division, I.C.I. Ltd., at Birmingham.

▶ Mr. A. L. Carr has left The Mond Nickel Co., Ltd., and has joined the Research Department, Metals Division of Imperial Chemical Industries Ltd.

▶ Mr. B. N. Das has left India for the U.S.A. where he is studying mechanical engineering at the University of Illinois.

▶ Dr. D. W. Davison has left T. S. Skillman and Co. Pty., Ltd., North Sydney, Australia, and is returning to the U.K.

▶ Mr. D. O. Gilbey has transferred from Bibiani (1927) Ltd., to the staff of the Ashanti Goldfields Corporation Ltd., Gold Coast.

▶ Dr. A. T. Green, O.B.E., has been elected first President of the newly-formed Institute of Ceramics, and Mr. R. A. Kirkby, J.P., Dr. J. R. Rait, and Dr. James White have been elected Members of Council.

▶ Dr. H. K. Hardy has been awarded the degree of D.Sc.

▶ Mr. J. C. Howard and Mr. H. J. G. Goyns have been appointed to the Board of Efco (South Africa) (Pty.) Ltd., a new subsidiary of Efco Ltd.

▶ Dr. B. B. Hundy has left the British Iron and Steel Research Association, and has joined Steel, Peech and Tozer as a Senior Research Metallurgist.

▶ Mr. R. S. Jackson has left the British Non-Ferrous Metals Research Association to take up the appointment of Works Metallurgist to Deloro Stellite Ltd.

▶ Mr. L. W. Johnson has been appointed Assistant Manager of the Development and Research Department of The Mond Nickel Co., Ltd.

▶ Mr. S. McCafferty has relinquished his appointment as Melting-Shop Manager to Wm. Beardmore and Co., Ltd., to become Technical Consultant to the Stabilimenti Siderurgici of the Terni Società per l'Industria e l'Elettricità, Italy.

▶ Dr. S. E. Mayer has left Standard Telecommunication Laboratories Ltd., and has gone to the U.S.A., where he has joined the Transitron Electronic Corporation, Melrose, Mass.

▶ Mr. H. Parnam has been appointed Director of Research to the Basic Division of General Refractories Ltd. at their Group Central Research Laboratories, Worksop.

▶ Mr. W. F. Randall has transferred from the Greenwich Works of the Telegraph Construction and Maintenance Co., Ltd., to the Telcon Works, Manor Royal, Crawley.

▶ Dr. E. C. Rhodes has been appointed Assistant to the Manager of the Development and Research Department, The Mond Nickel Co., Ltd.

▶ Mr. N. B. Rutherford has joined British Oxygen Engineering Ltd. as Senior Metallurgist.

▶ Dr. C. S. Smith has been granted a year's leave from his position as Professor of Metallurgy and Director of the Institute for the Study of Metals, University of Chicago. After attending the International Conference on the Peaceful Uses of Atomic Energy in Geneva as an advisory member of the U.S. delegation, he will then carry out research into the history of science, principally in London, under grants from the Guggenheim Foundation and the U.S. National Science Foundation.

▶ Dr. C. J. Smithells has left the British Aluminium Co., Ltd., and has joined Magnesium Elektron Ltd.

▶ Mr. L. Stansfield has resigned his post with the Steel Company of Wales, Ltd., to become Chief Metallurgist to Joseph Sankey (Manor Works) Ltd.

▶ Mr. A. Sutherland has taken up the appointment of Managing Director with Watson-Norie Ltd., Newcastle-on-Tyne.

▶ Dr. J. F. Watkinson has resigned from the staff of the Fighting Vehicles Research and Development Establishment, Ministry of Supply, to join the B.S.A. Group Research Centre, Sheffield.

▶ Mr. T. Watson, a Director of General Refractories Ltd., has been elected President of the Refractories Association of Great Britain for the session 1955–56.

▶ Mr. F. T. Wheelwright has left the U.K. for Malaya, where he has been appointed Technical Assistant to the Eastern Smelting Co., Ltd., Penang.

▶ Mr. A. N. Whiting has taken up an appointment as Steel Specialist with African Oxygen and Acetylene (Pty.) Ltd., Johannesburg.

▶ Dr. B. C. Woodfine has left the British Iron and Steel Research Association to join the Atomic Energy Department of the General Electric Co., Ltd., at the Fraser and Chalmers Engineering Works, Erith, Kent.

Obituary

Captain C. A. Ablett, O.B.E., Chairman and Managing Director of the Cooper Roll Bearings Co., Ltd., on 18th July, 1955. The founder of the Ablett Prize awarded annually by the Institute for a paper written by a junior engineer, Captain Ablett was elected an Honorary Vice-President of the Institute in 1949.

Mr. R. T. Bush, of Harrisons (London) Ltd., on 16th March, 1955.

Mr. F. Gardner, of Thornton Heath, Surrey, on 19th December, 1954.

Mr. Peter K. Rylands, of Warrington, Lancs., on 2nd May, 1955.

Mr. E. J. Thomas, of Swansea, in July, 1955.

Mr. A. Walker, of Newcastle-under-Lyme, on 11th July, 1955, as the result of an accident.

Monsieur Humbert de Wendel, of Hayange, Moselle, France.

CONTRIBUTOR TO THE JOURNAL

P. W. Wright, B.Sc.—Scientific Officer in the Physics Department, Battersea Laboratories of the British Iron and Steel Research Association.

Mr. Wright was born in 1928. He studied Physics at Woolwich Polytechnic, where he graduated with 2nd Class Honours in 1950. He then joined the British Iron and Steel Research Association, and until 1954 he worked in the Physics Department of the Swansea Laboratories. Since April, 1954, he has been working at Battersea, where he is a member of a small team investigating the deformation of metals at high rates of strain.

P. W. Wright

IRON AND STEEL ENGINEERS GROUP

Meeting of Junior Engineers

A Meeting of Junior Engineers will be held in London from **Monday to Thursday, 26th to 29th September, 1955.** In the absence of Mr. W. M. Larke, Chairman of the Engineers Group, the Hon. R. G. Lyttelton, Past-President of The Iron and Steel Institute, will be in the Chair.

The object of the meeting is to provide an opportunity for the younger engineers and operators in the iron and steel and associated industries to discuss engineering problems and visit works of interest; any members of the iron and steel and associated industries will be welcome at the meeting provided they are below the age of 35, whether they are members of The Iron and Steel Institute or not.

The following is the programme (the sessions on 26th September and the morning of 29th September will be held at 4 Grosvenor Gardens, London, S.W.1):

Monday, 26th September

3.30–4.30 P.M.—Lecture on: "*The Corby Works of Stewarts and Lloyds Ltd.*," by J. Daniel and D. Bird

4.30 P.M.—Tea

5.0–6.0 P.M.—Presentation and discussion of: "*Guides and Strippers for Rod and Bar Mills*," by F. Starkey (Buckley and Taylor Ltd.) (Published in the January, 1955, issue of the *Journal*).

Tuesday, 27th September

All-day visit by bus to the Ford Motor Co., Ltd., Dagenham, with lunch

7.0 P.M.—Dinner at the Rembrandt Hotel, Kensington, London, S.W.7.

Wednesday, 28th September

All-day visit by train to the Corby Works of Stewarts and Lloyds Ltd., with lunch.

Thursday, 29th September

10.0 A.M.–12.0 P.M.—Lecture on: "*The Iron and Steel Industry of Sweden*," by S. Fornander (Director of Research, Jernkontoret, Stockholm), followed by discussion.

Engineers Group Meeting

A half-day meeting of the Engineers Group will be held at the Engineers' Club, Manchester, on the morning of **Thursday, 20th October,** in connection with the National Fuel Efficiency Exhibition. Mr. J. F. R. Jones, of John Summers and Sons, Ltd., will be in the Chair, and Dr. W. S. Walker of the Round Oak Steel Works Ltd., will present a paper on "*Fuel Efficiency in the Iron and Steel Industry.*" (See separate insert in this issue).

INSTITUTE OF METALS

Students' Essay Prize Competition

The Council of the Institute of Metals will present this year a first and second prize of 25 and 15 guineas respectively for the best essays submitted in accordance with the regulations of the competition. Half of each prize will be in the form of scientific, technical, or other appropriate types of books, to be selected by the prize-winners. The competition is open to all Student Members of the Institute, and all Associate Members of Local Sections and Members of Associated Societies who are eligible for student membership of the Institute, provided that they are within the normal age limits (17–25 years).

The choice of subject is left to the competitor, but subjects relating exclusively to extraction or ferrous metallurgy are ineligible. Essays should not exceed 3500 words.

Further details are available from the Secretary of the Institute of Metals at 4 Grosvenor Gardens, London, S.W.1. Entries for the present competition must be submitted to the Secretary by not later than 1st January, 1956.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Ninth Junior Steelmaking Conference

The Ninth Junior Steelmaking Conference was held at Ashorne Hill on 22nd and 23rd June, 1955, under the general chairmanship of Mr. W. Geary. The first session, at which the Chairman was Mr. D. Hadfield, was devoted to the use of operational research methods in relating steel quality to steelmaking practice, and opened with a paper by Mr. H. A. Longden who described a simple graphical method of separating the effect of two variables so that, in the instance described, ferro-manganese yields could be satisfactorily predicted.

Mr. D. R. G. Davies, in presenting the second paper, showed that the reasons for the erratic occurrence of periods of bad quality could often be revealed by simple time-base charts; however, more detailed analysis by regression methods was usually then necessary to separate the effects of several variables and to assess their importance quantitatively. Experimental changes in the method of production or alterations in certain variables outside their normal range could give a quick means of reducing defectives, but Mr. Davies pointed out that these tests must be carefully planned for reliable results.

The last paper on this subject was given by Mr. H. G. Jones, who compared the treatment of routine data and the data obtained from a factorial trial, and gave an example in which quite different, albeit complementary, results were obtained from such sets of data.

Group and open discussion proved that this subject was of great interest and that the potential uses of operational research were realized by steelworks' operatives.

The second session, at which the Chairman was Mr. A. Fraser, was devoted to the commissioning and maintenance of an open-hearth furnace, and Mr. J. S. Curphey and Mr. H. T. Brodie spoke on tilting and fixed furnaces respectively. These talks promoted lively discussion on both methods and materials, and it was evident that the descriptions of the different practices used by various steelworks were of great interest.

Conference on Works Transport

A Conference on Works Transport was held at Ashorne Hill on 5th and 6th July, under the Chairmanship of Mr. C. H. T. Williams, when the main subject was methods of traction, with special reference to the relative merits of steam and diesel locomotives for iron and steelworks use.

The first session opened with a paper by Mr. M. F. Barnard on "*British Railways under the Transport Act of* 1953." The draft scheme of charges for the proposed new rates laid down the method for calculating charges based on loadability, i.e. the amount of freight that could be loaded and safely carried in a 10-ton, four-wheeled vehicle, and on the cost of services. The latter had been based on a very high average which, in effect, meant that new maximum charges could be up to 300% of present rates. The B.T.C. had also said that the scheme was not intended to bring about a general increase in freight revenues. For railway monopoly traffic, however, the traders' only safeguard would be 'reasonable maxima.'

The next paper was by Mr. M. D. J. Brisby and Mr. J. H. Turnbull, and was devoted to "*Locomotive Utilization and Availability.*" This consisted of a series of detailed analyses of the cost of an effective locomotive

working hour. Considering all the factors involved (availability, utilization, capital cost, etc.) the speakers demonstrated that, on the conclusion that three diesels could replace four steamers, a diesel fleet was basically a more economic proposition than a steam fleet.

Mr. H. E. Bottle then presented a paper on "*Radio Communications on Locomotives*," and the first day's proceedings were concluded with a paper by Mr. G. K. Tatterson and Mr. R. S. Brunton on "*Methods of Overcoming Specific Difficulties with Locomotive Working*," illustrated by a series of case histories.

The second session of the conference opened with a paper by Mr. E. R. S. Watkin and Mr. R. T. Ribbons, who discussed the best sizes and numbers of locomotives required in works. Mr. Watkin gave a comparative table, classifying and comparing the various ratings of steam and diesel locomotives, and suggesting the working conditions for which each grade was most suited. In his opinion, the 15-in. and smaller rating steam locomotives should now be considered obsolescent at the larger works. He made a plea for a restriction on the number of different sizes and types of locomotives employed; every additional size or type caused a reduction in interchangeability and standardization.

Mr. R. H. Fett then discussed "*Diesel Locomotive Drives—Electrical, Mechanical, and Hydraulic.*" He reviewed current design practice and developments under each heading.

The final paper on "*Other Shunting Devices*" was given by Dr. H. R. Mills, who reviewed developments in various types of light auxiliary movers. These fell into two main groups: (i) Mobile self-propelled machines running either on or between the rails, usually on pneumatic tyres, and (ii) machines fixed at a particular site for operating within a limited range. He dealt at some length with tippler gravity systems and the use of wagon traversers for transporting a wagon from one line to another. By providing shunting devices of the types described and improving the layout of sidings, it might be possible to reduce the number of locomotives required or to employ them more fully on other duties. Auxiliary moving devices could usefully be employed much more widely in iron and steelworks with consequent economies in transport costs.

Over 100 representatives of iron and steelworks, heavy industry, and locomotive-building interests from both home and abroad attended the conference which, in addition to the scheduled papers, included a series of discussion sessions.

B.I.S.R.A. Survey

The fourth annual issue of the B.I.S.R.A. *Survey* has recently been published, and contains details of some of the developments and advances made in various fields during the past year. These include a furnace-scanning periscope, recovery of sulphuric acid from waste, ingot handling and soaking-pit operation, sinter cooling, rapid heating of ingots, work on strain gauges, and on metal fatigue. An article on the rapidly expanding advisory services offered to industry by the Association is also included.

AFFILIATED LOCAL SOCIETIES

The following are the lists of officers for the session 1955–56:

Ebbw Vale Metallurgical Society

President
J. F. Smith
Vice-President
W. H. R. Bird, M.A., B.Sc.
Hon. Treasurer
T. Jones
Hon. Joint Secretaries
W. B. Williams — F. W. Lewis
Committee

J. J. Beese	F. Llewellyn
W. J. Davies	J. T. Mills
J. K. Edwards, M.A.	D. L. Mills
P. Edwards, A.I.I.A.	H. F. Padbury, A.I.M.
A. W. Ellis, A.M.I.E.E.	F. E. Probyn
W. Goatman	R. C. Powell, B.Sc.
I. Giddings	J. Thickins, B.Sc.
W. D. Jenkins, B.Sc.	W. E. Williams

Newport and District Metallurgical Society

President
G. H. Latham, LL.D., J.P.
Hon. Secretary — T. G. Grey-Davis
Hon. Treasurer — C. J. Morgan, L.I.M.
Committee
C. I. F. Mackay (*Chairman*)

H. R. Davies	H. H. Stanley, A.Met., F.I.M.
B. Jones, D.Sc., F.R.I.C.	J. G. Vinsen, B.Sc., A.M.I.E.E.
R. A. Owen-Barnett, M.Sc.	C. B. Pennington
H. T. Roberts, L.I.M.	

J. E. Wells, B.Sc., F.R.I.C., A.Met.

North Wales Metallurgical Society

Chairman
R. L. Willott
Vice-Chairman
C. H. Bacon
Hon. Treasurer — S. Andrew
Hon. Secretary — S. Weir
Hon. Assistant Secretary — J. B. Edwards
Hon. Press Secretary — P. R. Higginson
Committee

H. Edwards	G. Millington
M. Hall	A. D. Osborne
H. H. Johnson	E. Taylor-Austin
L. Leech	J. Till

NEWS OF SCIENCE AND INDUSTRY

Symposium on Mineral Resources Policy—London

A Symposium on Mineral Resources Policy is being organized by the Institution of Mining and Metallurgy on **22nd September, 1955.** The Symposium, which will be held in the Hall of the Royal Society of Arts, John Adam Street, Adelphi, London, W.C.2, will comprise a discussion on six papers dealing with the mineral industry in various countries, and possible approaches to greater mineral productivity.

Transfer of the Iron, Steel, and Metals Division to the Board of Trade

The Government has decided to transfer to the Board of Trade the responsibilities hitherto exercised by the Ministry of Supply in relation to the iron and steel and non-ferrous metals industries and the engineering industry.

The Division will retain its title and the various matters will be dealt with by the same offices as before.

The Minister of Supply will continue to exercise his responsibility in respect of the aircraft and light metal industries.

The transfer took effect on 18th July and the Division is now in the Headquarters Building of the Board of Trade, Horse Guards Avenue, Whitehall, S.W.1.

Institute of Ceramics

The study of ceramics in this country has recently received formal recognition by the formation of the Institute of Ceramics Ltd. A Committee representing the British Ceramic Society, the British Pottery Manufacturers' Association, the National Federation of Clay Industries, the Refractories Association of Great Britain, and the Institute of Clayworkers, has been responsible for the inception of this new Institute, and on 16th June the first Council of the Institute was confirmed in office, with Dr. A. T. Green, O.B.E., as President.

Membership of the Institute of Ceramics is open to citizens of the U.K., and is divided into three main classes: Licentiates, Associates, and Fellows. The qualifications for these three grades of membership are laid down in the Bye-Laws of the Institute, and enquiries should be addressed to the Secretary of the Institute (Mr. G. H. Stewart) at Federation House, Stoke-on-Trent. The Institute will also maintain a register of qualified ceramic technologists, and will later inaugurate a register of professional appointments available.

New Brightside Subsidiary

The Brightside Foundry and Engineering Co., Ltd., have formed a new wholly-owned subsidiary, Brightside Heating and Engineering Co., Ltd., to take over the continuously expanding activities of the heating, air treatment, and pipework divisions of the parent Company. Mr. Ambrose Firth has been appointed Chairman, and Mr. T. C. Firth, Mr. W. S. Richards, and Mr. W. B. James, Directors.

New Efco Subsidiary in South Africa

Efco Ltd. has recently formed a new subsidiary company in South Africa, in collaboration with its South African agents, D. Drury and Co., Ltd. The new Company is named Efco (South Africa) (Proprietary) Ltd., and the Board will consist of J. A. Monks and J. C. Howard, who are also Directors of the parent company, and, as South African members, A. D. Hodgson, R. P. Hacking, and H. J. G. Goyns. The Registered Office is in Johannesburg.

The Company will supply all types of electric furnace equipment for melting and heat-treatment of metals.

Slabbing and Blooming Mill for Turkey

A new 34-in., 2-high reversing slabbing and blooming mill plant, claimed to be capable of an output of 400,000 ingot tons per year, is being erected at the Karabuk Iron and Steel Works of the Summerbank General Directorate, Ankara, Turkey.

When working to capacity, the mill will operate 16 shifts per week and 50 weeks per year, and will roll 3-ton ingots either 20½-in. mean square for the production of blooms or 35 in. × 12 in. for the production of slabs. The bloom sizes will range from 12-in. square maximum to 6-in. square minimum, and slabs will be rolled up to 30 in. wide × 5 in. thick.

The equipment comprises the approach, working, and runout tables, the 34-in. mill and drive with sideguard manipulators, and ingot weighing and turning device, and hot-cropping and dividing shear with stop and measuring gear, a slab pusher and transfer bed, and the tables and transfer gear for feeding the blooms either direct or *via* a wash-heating furnace to the existing 28-in. structural mill. All the roller tables are group-driven through mitre gears and line shafts and have forged or cast rollers according to the duty or the position in the plant. These table rollers and drives run in roller bearings throughout and are of frame and unit construction.

On the approach table preceding the 34-in. mill is an overhead ingot-weighing device fitted with an automatic weight-recording unit. The weighing machine is incorporated in the lifting and turning unit, which will allow the ingot to be presented to the mill either large or small end foremost according to requirements. This unit is controlled from an operating pulpit located adjacent to it.

The mill train has 36-in. dia. rolls, 84 in. long in the barrel, running in fabric bearings lubricated by water and driven through universal spindles and a 41½-in. centre pinion housing from a D.C. reversing motor; the latter has a working peak of 14,000 h.p. at 60 r.p.m. and a cut-out peak of 16,000 h.p. at the same speed. The speed of the mill is 0/60/150. The rolls have a maximum lift of 36 in. and are powered to give a screwing speed of 160 in./min. The top roll is balanced by opposed screws and is provided with quick-release gear to facilitate roll-changing. Both rolls are changed simultaneously and are withdrawn from or entered into the mill by a power-operated sledge.

The manipulators are of the full-sideguard type and are fitted with tilting fingers on the ingoing side. These manipulators are designed to handle all products down to 6-in. square minimum, and are powered to give a traversing speed of 164 ft./min. and incorporate patented tilting finger drive.

The hot-bloom shear, which is of the down-adjusting, upcutting type, is electrically operated and powered to give a blade load of 800 tons and has a maximum daylight between the blades for accepting 12-in. high blooms and a blade length suitable for 30-in. wide slabs. It is equipped with a crop-end pusher for the discharge of the end pieces and a retractile roller to permit such crops to drop freely into the collecting bins *via* a chute and a butterfly switch. The stop and measuring gear is electrically operated for both lifting and traversing and is calibrated to measure blooms from 1·25 to 5·5 m. Located immediately behind the shear is a pusher and transfer bed for slabs.

The runout table from the shear is so located that the blooms can be delivered direct to the 28-in. structural mill or can be side-transferred on a skid bed and charged in a wash-heat furnace. They are then delivered to the 28-in. mill *via* tables and transfer gear. The main D.C. auxiliary motors are provided with Ward-Leonard control.

The consulting engineers for this contract are the International Construction Co., Ltd., and the mechanical equipment is being supplied by the Brightside Foundry and Engineering Co., Ltd.

New Installations at Capital Steel Works

Modernizations to the steel-producing plant of Arthur Balfour and Co., Ltd., have included the installation of new annealing and heat-treatment plant at the Capital Steel Works. Three new batch-type furnaces have been erected, together with an electric charging machine and two fabricated steel loading tables.

Combination Rolling Mill

To meet the need in this country for a really versatile ferrous and non-ferrous rolling mill, American-designed 'Stanat' machines are now being manufactured under licence by Albert Mann's Engineering Co., Ltd. The equipment, which will be known in the U.K. as 'Stanat-Mann,' is a 2-high/4-high combination rolling mill, and is available in 1½ in. and 5 in. × 8 in. and 2¼ in. and 8 in. × 8 in. sizes. To make the change from 2-high to 4-high, the large rolls are separated and two smaller rolls are inserted between the large ones, which then become 'back-up' rolls.

Dimensional Limit Indicator

An instrument designed to give an instantaneous indication of any variation in the dimensions of metal strip during the final drawing process has been manufactured by Sutton Coldfield Electrical Engineers. The instrument gives an immediate aural and visual warning of changes outside predetermined limits, and, if required, can be made to stop the mill. The original unit was designed for the inspection of strip approx. $\frac{3}{16}$ in. wide and 0·030 in. thick, but with the use of suitable guides strip of any dimensions may be accommodated. Tolerance limits can be set within a range of $\pm$ 0·0003 in. to $\pm$ 0·01 in.

Recent Advances in Steel Technology

A report entitled " *Recent Advances in Steel Technology and Market Development*, 1954 " has been compiled by the Secretariat of the United Nations Economic Commission for Europe. Based on contributions made by eminent experts in steel technology, the report contains four papers on: Ore preparation, coke production, and blast-furnace practice; steelmaking developments; rolling and finishing; recent progress in the technique of market development. These items were selected for their potential value in increasing productivity and improving efficiency, thereby reducing costs.

A special introduction to the report has been written by Sir Charles Goodeve, O.B.E., D.Sc., F.R.S., Director of B.I.S.R.A., who anticipates a healthy future for a steel industry that keeps pace with technical advances in the age of nuclear energy.

Copies of the report, which contains 68 pages, including tables and diagrams, are obtainable from the Sales Section, European Office of the United Nations, Palais des Nations, Geneva, Switzerland, price 3*s*. 9*d*. each.

Work Study

A supplement to the April, 1955, issue of the British Productivity Council's Bulletin contains a summary of eight papers on work study in theory and practice which were presented at the B.P.C. Work Study Conference in March. The papers deal with the application of work study to the printing, furniture, and hosiery industries, its place in factories, and its use in smaller firms and for batch production. Copies of the supplement are available from the Council at 21 Tothill Street, London, S.W.1, price 9*d*.

Changes of Name and Address

The Association des Ingénieurs sortis de l'École de Liège has removed to new premises at 22 rue Forgeur, Liège, Belgium.

Arthur Balfour and Co., Ltd., have recently opened a new office and warehouse at 55 Park Place, Cardiff (Tel. Cardiff 29715). The Area Manager is Mr. C. R. Hope.

All departments of the British Scientific Instrument Research Association have now removed to Southill, Elmstead Woods, Chislehurst, Kent.

W. Edwards and Co. (London), Ltd., will in future be known as Edwards High Vacuum Ltd.

The Empire Council of Mining and Metallurgical Institutions will in future be known as the Commonwealth Council of Mining and Metallurgical Institutions, and the forthcoming Congress in 1957 will accordingly be the Sixth Commonwealth Mining and Metallurgical Congress.

Mactaggart and Evans Ltd., Sondes Place Research Institute, Dorking, will in future be known as the Sondes Place Research Laboratories Ltd.

The Mond Nickel Co., Ltd., Henry Wiggin and Co., Ltd., Mond Nickel (Retirement System) Trustees Ltd., The Clydach Estates Ltd., The Tareni Colliery Co., Ltd. —The Registered Offices of these Companies are now at Thames House, Millbank, London, S.W.1 (Tel. Victoria 3888).

The firm of Turkiye Demir ve Çelik Fabrikalari Muessesesi, Karabuk, Turkey, will in future be known as Turkiye Demir ve Çelik Işletmeleri umum Mudurluğu.

The United Strip and Bar Mills, a wholly-owned associate of Steel, Peech and Tozer, have ceased to trade under a separate title, and their activities are now carried out in the name of Steel, Peech and Tozer.

Industrial Publications Received

Details of the manufacture and use of ' Densyl ' silica refractory bricks are given in Publication No. 102. 4M. M.P. 6/55, published by General Refractories Ltd.

General and detailed information on the ' E-Mil ' range of laboratory glassware and thermometers—Catalogue No. 7—H. J. Elliott Ltd.

Low-lift electric platform truck, Models M4 (2-ton capacity) and M6 (3-ton capacity)—Bulletin B.1038—Yale and Towne Manufacturing Co.

Brochures on distant-transmission telemetering equipment for flow, level, pressure, etc. (Catalogue E231), and on miniature equipment for the recording of temperature, flow, pressure, level, draught, and revs. (Catalogue E.500). Bailey Meters and Controls Ltd.

DIARY

31st Aug.–7th Sept.—British Association for the Advancement of Science—Annual Meeting—Bristol.

19th–23rd Sept.—Institute of Metals—Annual Autumn Meeting—Buxton, Derbyshire.

1st–15th Sept.—Engineering, Marine, Welding, and Foundry Trades Exhibition—Olympia, London, W.14.

21st Sept.—North Wales Metallurgical Society—" *The Industrial Application of Atomic Energy*," by A. D. Merriman—County Primary School, Plymouth Street, Shotton, Nr. Chester, 7.15 p.m.

22nd Sept.—Institution of Mining and Metallurgy—Symposium on Mineral Resources Policy—Royal Society of Arts, John Adam Street, Adelphi, London, W.C.2, 10.0 a.m.

26th–29th Sept.—Iron and Steel Engineers Group—Meeting of Junior Engineers—London.

3rd–6th Oct.—International meeting on " *Le Fer à Travers les Âges* "—Palais Ducal, Nancy, France.

6th Oct.—Leeds Metallurgical Society—" *Vacuum Melting and Vacuum Heat Treatment*," by B. C. Woodfine—Large Chemistry Lecture Theatre, University of Leeds, 7.15 p.m.

TRANSLATION SERVICE

(The previous announcement was made in the August, 1955, issue of the *Journal*, p. 381.)

Translation Available

No. 505 (German). M. Hansen: " Model Experiments in the Change of Direction of Flow in the Port End of a Cold-Gas-Fired Open-Hearth Furnace." (*Archiv für das Eisenhüttenwesen*, vol. 26, May, pp. 243–251).

Translation in Course of Preparation

(German). G. Boos and J. Willems: " Temperature Measurements in the Open-Hearth Steel Plant." (*Stahl und Eisen*, 1955, vol. 75, July 14, pp. 900–905.)

ABSTRACTS OF CURRENT LITERATURE AND BOOK NOTICES

Iron and Steel Manufacture and Related Subjects

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ORES—MINING AND TREATMENT

Teamwork on Taconite. R. H. Ramsey. (*Eng. Min. J.*, 1955, **156**, Mar., 71–93). An account is given of the work leading up to the decision by Erie Mining Co. to install a commercial plant to produce 7·5 million tons of pellets annually from taconite concentrates. The process and projected plant are described, with site plans, flow sheets, and equipment diagrams.—K. E. J.

Preparation of the Blast-Furnace Charge at Mont-Saint-Martin. M. Aubert. (*Centre Doc. Sidér., Circ. Inf. Tech.*, 1955, **12**, (2), 321–343). Preparation of the charge involves the crushing of ore and the agglomeration of fines and also of recovered flue-dusts and other waste dusts. Crushing and screening operations are summarized. The Greenawalt agglomeration plant, which handles 1200 tons/day, is described with the aid of a diagram, and details are given of its operation and of the agglomerate produced. Influence of charge preparation on the operation of four blast-furnaces over a period of two months was examined.—T. E. D.

Burden Preparation at Espérance-Longdoz. Schmidt Rotary Kilns. M. Gérard. (*Centre Doc. Sid., Circ. Inform. Tech.*, 1955, **12**, (1), 133–168). The three Schmidt kilns installed in 1914, 1928, and 1931 respectively were used almost entirely for agglomerating flue-dust, until 1947. Since then, Saint-Pierrmont ore fines have been agglomerated, and the plant has been overloaded. A critical examination is made of the performance of the plant, on account of the low production rate and high cost of maintenance. Details of the plant, labour requirements, services, and raw materials are given. The movement of materials in the kiln is discussed, and the mechanism of agglomeration is outlined. Regulation of operation with different materials is described, and operating data are recorded. The properties of agglomerates are given, and the merits of the method are summarized.—T. E. D.

Research on Established Processes. D. W. Gillings. (*Research*, 1955, **8**, Jan., 2–7). The introduction of new methods into processes of heavy industry involves special problems. Research on iron-ore sintering illustrates the benefits to be gained from a sequence of experiments performed alternately on a plant in full production and on experimental equipment. The weakness of plant-scale work alone is emphasized.—K. E. J.

Quartz Flotation with Anionic Collectors. A. M. Gaudin and D. W. Fuerstenau. (*Min. Eng.*, 1955, **7**, Jan., 66–72). The concept of the electrical double layer has been applied to quartz; the potential is determined by *p*H. The behaviour of sodium, barium, aluminium, laurate, and oleate ions in solution is described.—K. E. J.

Recent Progress in the Flotation Process for Concentrating Minerals. P. Chataignon. (*Rev. Tech. Luxembourg.*, 1954, **46**, Oct.-Dec., 258–265). Flotation of ferrous and non-ferrous materials is considered. Work on iron ores in America is briefly described.—B. G. B.

Silicon Carbide Brick Lengthens Dust Collector Life. W. D. Latiano. (*Iron Age*, 1954, **174**, Dec. 9, 160–161). Hard-burned brick linings of cyclone dust collectors attached to a Greenawalt sintering machine required replacing in a matter of months; a lining of silicon carbide bricks is in good condition after 7 years.—D. L. C. P.

Adsorption of Dodecylammonium Acetate on Hematite and Its Flotation Effect. A. M. Gaudin and J. G. Morrow. (*Min. Eng.*, 1954, **6**, Dec., 1196–1202). The isotherm for the adsorption of amine from aqueous solution on to the surface of hematite has been established, and results are also given concerning the reversibility of adsorption, the effect of *p*H, contact angles on hematite and quartz, and the work of adhesion and energy of adsorption.—K. E. J.

Some Observations on the Application of the Law of Pulsation to Metallurgical Processes. W. Küntscher. (*Met. u. Giesserei Techn.*, 1954, **4**, Dec., 533–536). An ' optimum reaction rhythm ' in gas reaction can be attained by impulse pressure or by pulsed suction. In laboratory tests, the strength and reducibility of sinter were increased by using pulsed suction. The author advocates the application of ' rhythm ' to many metallurgical processes, such as the additions of lime and ore in open-hearth refining, and the cooling of ingot moulds in a water bath agitated by a pulsating stream of compressed air.—R. A. R.

Development of Chemical Treatment of Low-Grade Iron Ores at Appleby-Frodingham. L. Reeve. (*J. Iron Steel Inst.*, 1955, **181**, Sept., 26–40). [This issue].

FUEL—PREPARATION, PROPERTIES, AND USES

The Relation between Particle Size and the Reactivity of Solid Fuels. S. Traustel. (*BWK*, 1955, **7**, Jan., 13–15). A general theory of the relation is developed in terms of characteristic, dimensionless parameters.—P. F.

Effect of Inhomogeneity of Luminous Flames on Their Radiation. W. Pepperhoff and G. Grass. (*Arch. Eisenhüttenwesen*, 1955, **26**, Jan., 9–18). Every flame is inherently inhomogeneous because it incorporates all stages of combustion.

The radiation of inhomogeneous flames in relation to temperature and absorption were studied. Temperature measurement by the inverse spectrum and calculation from the colour and black-body temperatures gives, for both methods, values which are not clearly defined with respect to their position between the lowest and highest temperature of the flame. The mean total radiation of an inhomogeneous flame calculated from the colour and black-body temperatures is, however, in fair agreement with the true temperature. The error can be corrected by empirical factors.—T. G.

"How will Nuclear Power Affect Your Customers." L. R. Hafstad. (*Blast Furn. Steel Plant*, 1955, **43**, Feb., 228–231, 234, 251, 255). The economics of the production of electricity by atomic energy are discussed in detail.—B. G. B.

Measurement of Oil Quantities by Means of an Orifice Plate. M. Hansen and E. Hoffman. (*Stahl u. Eisen*, 1955, **75**, Jan. 27, 100). Standard orifice plates should not be used to measure the flow of fuel oil because of its very high viscosity and the great changes in viscosity on warming. The authors describe results of quantity measurement of fuel oil with a double bevelled orifice plate developed by Witte. The plate is 3 mm. thick and has a 50° bevel upstream and a 45° bevel downstream. When the Reynolds' number changes from 10,000 to 100 on warming, the error using a standard orifice plate is about 10%, whereas with the Witte orifice it is only 1·5%.

Present Methods of Coal Preparation in Western Germany. Dust Precipitation and Flotation. A. Gotte. (*Z. V. d. I.*, 1955, **97**, Feb. 1st, 97–104). Current developments are surveyed. Among appliances for dust precipitation a hydraulic method of sieve tensioning deserves mention. The Convertol method of flotation is discussed and reference is made to dehydration by vacuum filters and centrifuges.—J. G. W.

The Representation of Coal Cleaning Results. R. M. Horsley and P. F. Whelan. (*Canad. Min. Met. Bull.*, 1955, **48**, Feb., 74–83). A concise account is given of the various methods of representing coal-cleaning operations. The methods fall into five groups: block distribution diagrams, washability curves, middlings curves, error curves, and efficiency formulæ.

Small Unit Coal-Preparation Plant. (*Iron Coal Trades Rev.*, 1955, **170**, Feb. 25, 443–445). A prototype Norton Mark II small standard coal washing unit, designed to treat a throughput of 50 tons/hr., operating at the Shuttle Eye Colliery, Yorkshire, is described.—G. F.

Dense Media Coal Washing: New "Neldco" Unit at Yorkshire Main Colliery. (*Iron Coal Trades Rev.*, 1955, **170**, Feb. 11, 317–318). Details of a new "Neldco" dense-media coal-washing plant, using magnetite as the medium and treating 100 tons of − 6 in. to + 2 in. sized coal per hour, at Yorkshire Main Colliery, are given.—G. F.

Combustibles and their Combustion. Examination of Three Particular Problems. R. Martin. (*Chaleur et Ind.*, 1954, **35**, Dec., 376–384). The problems examined are concerned with the combustion of a mixture of blast-furnace gas and natural gas, carbon monoxide, a mixture of hydrogen and nitrogen, and pure hydrogen.—T. E. D.

Burners for Gas and Oil. C. C. Eeles. (*Indust. Heating*, 1954, **21**, Oct., 1990–1992, 2152, 2160). The design, operation, and typical applications of burners using (*a*) gas and oil simultaneously, (*b*) gas or oil separately, and (*c*) a combination of (*a*) and (*b*) are discussed.—A. D. H.

Effects of Recent Knowledge of Atomic Constants and of Humidity on the Calibrations of the National Bureau of Standards Thermal-Radiation Standards. R. Stair and R. G. Johnston. (*J. Res. Nat. Bur. Stand.*, 1954, **53**, Oct., 211–215). Recent calculations of the Stefan-Boltzmann constant of total radiation and of the influence of water vapour in air on the transmission of radiation from standard lamps do not affect the thermal radiation standards.—B. G. B.

The Flow Pattern Factor in Fuel Research. J. H. Chesters. (*Sheffield Univ. Fuel Soc. J.*, 1954, **5**, 24–29). The importance of flow-pattern model work as a tool in fuel research is described and illustrated. Its application to open-hearth design is mentioned. (14 references).—D. L. C. P.

Productivity, Fuel Availability and its Efficient Use. K. T. Spencer. (*Engineer*, 1954, **198**, Dec. 24, 889–891; Dec. 31, 923–925). This paper, presented at a D.S.I.R. Conference on Research and Industrial Productivity, held in November, 1954, gives facts about the present fuel and power situation, and how that situation has come about during the last generation or two.—M. D. J. B.

Improvements in Plant and Operations at Pueblo Coal Washery. J. D. Price and W. M. Bertholf. (*Min. Eng.*, 1954, **6**, Dec., 1190–1195). In the washery of Colorado Fuel and Iron Corp., 23 primary tables and four rewash tables have been replaced by two 84-in., 3-compartment, 6-cell air-operated Jeffrey jigs; the coal is not now crushed before washing. The efficiency is improved and labour requirements are halved.—K. E. J.

New Coal Preparation Plant at Mansfield Colliery. (*Min. J.*, 1954, **243**, Dec. 24, 736–738).

Technical Mission of the "Commission des Cokes" in Great Britain and Germany. C. G. Thibaut. (*Publ. Inst. Rech. Sid.*, Série **B**, 1954, (24), Feb., 27 pp.). Research organizations, laboratories, and coke-ovens visited in Great Britain and Western Germany in 1952 are listed, together with an outline of work of interest going on at each of these places. Aspects of coke-quality in the U.K., Germany, the U.S.A., and France are discussed and compared.—T. E. D.

Metallurgical Coke from Washed Wheelwright Coal and its Effect on Blast Furnace Iron Tonnage. R. L. Gray and N. Isenberg. (*Amer. Inst. Min. Met. Eng., Proc. Blast Furn., Coke Oven, Raw Mat. Comm.*, 1954, **13**, 107–127). Since mechanization of its Wheelwright mine, the Inland Steel Co. has compared the use of washed and unwashed Wheelwright coal in the coking and blast-furnace plants. The authors discuss the improvements in chemical analysis, physical properties, and degree of uniformity in the metallurgical coke resulting from the use of washed coal, and give data indicating the significant increase in iron production accompanying the use of uniformly low-ash coke in the blast-furnaces.—G. F.

A Small Pressure-test Oven for Measuring Expansion Pressure Developed during Carbonization of Coal. H. E. Harris, E. W. Margel, and R. D. Howell. (*Amer. Inst. Min. Met. Eng., Proc. Blast Furn., Coke Oven, Raw Mat. Comm.*, 1954, **13**, 127–141). The authors give details of the design and operation of a small test oven for measuring the expansion pressure developed during coal carbonization. The oven has low initial, operating, and maintenance costs; uniform two-sided heating with a small coal charge; and a simple and short test cycle. Results are quoted showing reproducibility and good correlation with results from movable-wall ovens.—G. F.

The Influence of Mechanical Treatment of Coke on Its Quality. B. Kalinowski, A. Grossman, and F. Janta. (*Hutnik*, 1954, **21**, (10), 324–326). [In Polish]. The influence of transporting and screening equipment on the mechanical properties of coke was investigated. On the basis of the results the correct method of handling coke according to its strength has been suggested.—V. G.

Furnace Design for One Hundred Per Cent Natural Gas Firing. J. L. Jennings and J. R. Patton. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1954, **37**, 320–327). Open-hearth furnaces at the Granite City works of General Steel Castings Corp. are fired with 100% natural gas. The authors describe the type of burner used and give details of the furnace design.—G. F.

TEMPERATURE MEASUREMENT AND CONTROL

Temperature Control Systems for Fuel-Fired Galvanizing Baths. J. A. Hartnett. (*Instruments in Industry*, 1954, **1**, Dec., 239–240). The principle and operation are described of the Brown temperature-control system for batch operation of a galvanizing bath.—L. D. H.

The Portable Potentiometer . . . An Instrument of Necessity. D. J. Pearse. (*Indust. Heating*, 1954, **21**, Oct., 1970–1978, 2106). Various types of potentiometer are described, and the usefulness of the instrument in checking thermocouples is discussed. Methods of checking are given.—A. D. H.

Thermocouples. E. E. Hancox. (*Instruments in Industry*, 1954, **1**, Dec., 229–234). A brief survey is given of the historical development, and the principal types and applications of thermocouples.—L. D. H.

On the Quick Immersion Thermocouple and the Check Method of the Thermocouple Elements. Y. Wada. (*Sumitomo Metals*, 1953, **5**, Jan., 38–46). [In Japanese]. A survey is made of various methods of measuring liquid-steel temperature and studies are reported on the Schofield thermocouple.

Temperature Measurement in Industry. (*Berg. Hüttenmänn. Monatsh.*, 1954, **99**, Aug.-Sept., 172–176). An outline is given of modern methods and instruments for measuring temperature in industrial processes. All types and varieties of instruments are described in brief.—E. C.

Hot-Blast Temperature Controllers. P. S. J. Rao and R. V.

Tamhankar. (*Tisco*, 1954, **1**, Oct., 162–168). The principles of controllers are discussed and proportional, derivative, and integral controllers are described. A general description of the necessary control equipment and its operation is given. The frequency-response diagram is introduced and the method of matching the controller to the blast-furnace with its aid is shown.—L. E. W.

REFRACTORY MATERIALS

Combined Ceramic-Metal Construction. O. H. Schmidt. (*Technik*, 1955, **10**, Apr., 237–242). Suitable methods of joining ceramics and metals in engineering construction are discussed by reference to the physical properties of the two materials.—J. G. W.

South African Chromite: A Valuable Refractory Material. A. G. Thomson. (*Iron Steel*, 1955, **28**, Feb., 65–66). Following an outline of the properties of chromite refractories, brief details are given of the location, quantity, and quality of the most important South African deposits.—G. F.

Iron Spots in Silica Bricks, Part I—Their Occurrence and Development. Part II—Experiments on Blending Silica Raw Materials. J. Laning and G. R. Rigby. (*Gas Council Research Communication* GC 16, 1954, Sept. 16, 27–41). Information on the occurrence and implications of 'iron spots' in silica bricks was collected, and experiments made to elucidate their formation. Spots were artificially produced by metallic iron, hematite, pyrite, and siderite nuclei, but iron picked up in the preparation of the brick batch is considered the most likely source during production.—D. L. C. P.

Variables in the Load Test for Fire-Clay Refractories. W. E. Brown and R. B. Sosman. (*J. Amer. Ceram. Soc.*, 1954, **37**, Nov., 552–558). An investigation is reported into the A.S.T.M. load test and its possible improvement. The present test, which involves measuring the change in length of a specimen after heating under standard conditions, gives results which are a function of the size of specimen. It was found that the deformation/time curve at constant temperature is more reliable and informative.—D. L. C. P.

Castable Refractories: Where to Use Them to Best Advantage. H. G. Hart. (*Iron Age*, 1954, **174**, Dec. 30, 47–49). The properties and uses of refractory concretes are described, with particular reference to their application in various positions in iron and steel production.—D. L. C. P.

Refractories for the Blast Furnace. (*Ceramics*, 1954, **6**, Nov., 396–402). The conditions existing in blast-furnaces and hot-blast stoves and pipes are considered, and the properties of refractories used for lining them are described. The method of making carbon refractories is outlined and their growing applications to hearth and bosh linings is commented on.—D. L. C. P.

Systems Operating with Hot Blast—Refractories for Cowper Stoves. A. Rygaerts. (*Silicates Indust.*, 1954, **19**, Dec., 418–421; 1955, **20**, Jan., 25–30). The requirements for refractories in Cowper stoves from the point of view of quality and design, as well as their most efficient use in the stoves, are discussed.—P. F.

The Choice of an Appropriate Fireclay Lining. (*Fonderie*, 1955, Jan., 4340–4342). The factors governing the choice of fireclay linings for various types of melting furnaces are briefly discussed.—B. C. W.

Gun-Placed Silica Cupola Linings. T. E. Barlow and P. D. Humont. (*Amer. Ceram. Soc. Bull.*, 1954, **33**, Oct.. 301–306). A survey of gun patching is presented, including suggestions on the best method of handling the patching equipment and the optimum air and water pressures in the gun. Patches above the tuyeres should be concave and the composition of the patch be compatible with that of slag.

Utilization of Insulating Refractory Linings in Slot Type Forging Furnaces. G. M. McCormick. (*Indust. Heating*, 1955, **22**, Jan., 152–161). The advantages of spring-mounted insulated firebrick-lined forging furnaces over those lined with hard firebrick are discussed with reference to fuel consumption, productivity, maintenance, and scaling.—A. D. H.

The Manufacture and Use of Refractories in the South. C. A. Brashares. (*Indust. Heating*, 1954, **21**, Nov., 2315–2320, 2330, 2338). Industries using refractory materials in the Southern states of the U.S.A. are detailed. Raw materials and the manufacture of silica and fireclay products are discussed.—A. D. H.

Testing Open Hearth Refractories. G. R. Eusner and W. S. Debenham. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1954, **37**, 146–150). The authors discuss the necessity for routine testing of refractories in the steelworks. The characteristics of silica and basic bricks are outlined, and the choice of casting-pit refractories is considered.—G. F.

The Measurement of Internal Thermal Conductivity of Insulating Materials and Refractories. M. Signora and F. Baldi. (*Calore*, 1954, **25**, Dec., 559–564). [In Italian]. A detailed description is given of the apparatus developed to measure the thermal conductivity of cork, magnesium, asbestos, slag-wool, glass-wool, silica and alumina bricks, etc.—M. D. J. B.

Control Testing of Open Hearth Pit Refractories. C. N. Jewart. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1954, **37**, 150–152). A brief outline is given of the routine control testing of casting-pit refractories, particularly ladle bricks and stopper sleeves, nozzles, and heads, at the Lackawanna plant of Bethlehem Steel Co. Since the introduction of control testing, the life of ladle linings and teeming practice have been improved.—G. F.

Fireclay for Blast Furnaces. B. T. Day and R. F. Baley. (*Amer. Inst. Min. Met. Eng., Proc. Blast Furn., Coke Oven, Raw Mat. Comm.*, 1954, **13**, 6–11). The authors present data designed to give a broad basic understanding of fireclay used in blast-furnace plants. They deal mainly with mining and processing methods; shipping, storage, and preparation for use; specifications and chemical analysis; and the physical properties of chief interest to blast-furnace men.—G. F.

Specialised Refractories and Fuel Economy. (*Ceramics*, 1954, **6**, Aug., 257–261). The fields of use for the high-temperature insulating bricks and special-quality dense structural firebricks made by Morgan Refractories Ltd. are explained. Examples of thermal and financial savings resulting from the incorporation of high-temperature insulating bricks in intermittent furnaces are given.—D. L. C. P.

Modern Furnace Insulation. G. K. Stanfield. (*Sheffield Univ. Fuel Soc. J.*, 1954, **5**, 30–36). Thermal properties of insulating materials, and the use of special concrete and bricks for backing and hot-face insulation are considered. Examples illustrate furnace insulation design and the considerable economies obtainable. Modern insulating bricks are notable for light weight, low heat capacity, low thermal conductivity, high working temperature (up to 2800° F.), accurate dimensions, and ease of shaping.—D. L. C. P.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

Rebuilding the "D" Blast Furnace of the Tata Iron and Steel Co., Ltd. P. K. Chatterjee. (*Tisco*, 1955, **2**, Jan., 23–35). The author reviews in detail the construction and erection of the blast-furnace and its ancillary equipment.

Floating Blast-Furnace Construction. L. N. Misra. (*Tisco*, 1955, **2**, Jan., 36–40). The author describes how the superstructure of a blast-furnace shell was erected on temporary supports while foundations were prepared at the bottom. The superstructure was then lowered into position after the foundations and underframe were completed.—L. E. W.

New Plant Extensions at Renishaw Iron Company, Limited. (*Iron Coal Trades Rev.*, 1955, **170**, Jan. 28, 201–203). The Renishaw Iron Co., Ltd., has recently relined and extended No. 2 blast-furnace and installed a new materials-handling plant. A brief description is given of the equipment and new layout.—G. F.

Development in German Blast-Furnace Design and Practice. D. Knall. (*Blast Furn. Steel Plant*, 1955, **43**, Jan., 83–84, 96, 98). A review of German methods is presented. Automatic control of stoves, stove design and operation, gas sampling and temperature measurement in the stack of the blast-furnace, individual gas-flow measurements at each tuyere, and removal of scabs by blasting are described.

Report of Trials on the Accumulation of Heat in a D. Petit Cowper at the Louvroil Works. M. Moutot. (*Centre Doc. Sid., Circ. Inf. Tech.*, 1955, **12**, (2), 383–401). Blast for blast-furnace No. 2 at Louvroil is heated by a Petit Cowper and a Cockerill Cowper. The trials described examine the normal output of the two types of stove, the output of the Petit Cowper running under accumulating conditions, the amount of heat accumulated by the plant, and the practical yield expressed by the ratio of recuperable gas to gas burnt

in excess. The two types of stove are described, and results are given.—T. E. D.

Tests on Cowper Stoves. D. Sanna. (*Centre Doc. Sid., Circ. Inf. Tech.*, 1955, **12**, (2), 345–382). The storage of heat in Cowpers is investigated. The results of measurements of checker temperature at various levels are given graphically for both the heating and cooling cycles. The performance of stoves at various works is given, together with details of design and heat balance. It is recommended that the duration of heating and cooling cycles should be equalized, and that gas should not be cut off completely during the cooling cycle. Pressure drop through Cowpers at different works is reported, and the effect on performance is interpreted. Heat-transfer coefficients in checkers of different types are determined from temperature measurements. Recommendations on Cowper design are given.—T. E. D.

Blast Furnace Instrumentation. (*Metallurgia*, 1954, **50**, Dec., 285–286). A short illustrated account of instruments manufactured by George Kent Ltd., and installed in the Seraphim extensions at the Appleby-Frodingham Steel Company is given.—B. G. B.

International Committee for Low Shaft Furnace Research. (*Rev. Tech. Luxembourg*, 1955, **47**, Jan.-Mar., 40–43). A short account of the work carried out on the low-shaft furnace at Liège during 1953–1954 is presented.—B. G. B.

Pig Iron Made from Low-Grade Fine Ore and Non-Coking Coal. (*Metal Progress*, 1955, **67**, Jan., 81–86). A description is given of the low-shaft furnace sponsored by O.E.E.C. and erected in Belgium. The results obtained with the furnace during 1954 are outlined.—B. G. B.

Correlating Blast-Furnace Operating Concepts. C. E. Agnew. (*Steel*, 1954, **135**, Sept. 27, 90–96; Dec. 20, 84–88; Dec. 27, 68–71). Continuation of a series of articles (*see J. Iron Steel Inst.*, 1955, **180**, May, 73). Factors which influence the rate of reduction of ores and sinter are considered from operational and scientific evidence available. Reducibility of ores depends upon the conditions under which heat is applied and the thermal needs of other reactions; the amount of heat required is a secondary matter. The substitution of volatile-free for volatile-bearing magnetite reduces the fuel requirements for preparing the ore. As more sinter will be used in charges, changes in methods of blast-furnace control will become necessary. In this respect the relation between blowing rate and heat distribution is discussed.—R. A. R.

Combustion of Coke and the Descent of the Burden. Thibaut. (*Centre Doc. Sid., Circ. Inform. Tech.*, 1954, (2), 357–360). Burden descent is discussed in relation to the existence of a " dead man " and of voids in front of the tuyeres, and the effects of shutting off the blast and tapping are considered. The radial depth of the combustion zone can, in general, only be increased by lowering the blast temperature, which is not always feasible.—A. G.

Developments in Ironmaking at Appleby-Frodingham. G. D. Elliot. (*J. Iron Steel Inst.*, 1955, **181**, Sept., 1–16). [This issue].

Some Design Problems of the " Seraphim " Plant. I. M. Kemp. (*J. Iron Steel Inst.*, 1955, **181**, Sept., 61–70). [This issue].

Automatic Control of Thermal Processes in the Blast-Furnace. J. Spal. (*Hutnické Listy*, 1954, **9**, Dec., Supplement 4–8). [In Czech]. Control is exercised mainly at the Cowper stoves. Suitable instrumentation is discussed.—P. F.

Automatic Charging of Blast-Furnaces. S. Černoch. (*Hutnické Listy*, 1954, **9**, Dec., Supplement 8–13). [In Czech]. The MacKee type of controlled belt-charging is described, and details of equipment of this kind, but considerably improved by the author, are given.—P. F.

A Note on the Running of the Blast Furnaces of Monlevade Works with 100% Ore. J. Wscieklica. (*Bol. Assoc. Brasil Met.*, 1954, **10**, April, 97–109). [In Portuguese]. Modifications to the sinter plant caused three blast-furnaces to be run exclusively on ore for three months. The irregularities in operations resulting from this and the remedies effected are described.—P. S.

Continuous Analysis of Iron Blast Furnace Top Gas. D. J. Carney, A. J. Deacon, and T. L. Batina. (*Amer. Inst. Min. Met. Eng., Proc. Blast Furn., Coke Oven, Raw Mat. Comm.*, 1954, **13**, 142–163). Continuous top-gas analysers have been installed on two blast-furnaces at South Works of United States Steel Corporation. The authors describe the instruments, and discuss the accuracy and reproducibility of the results and their relationship to various operating variables. They conclude that the instrument is not particularly useful to the furnace operator, but has merit for research into blast-furnace reactions.—G. F.

An Examination of Equilibrium Constants of Reactions $FeO + H_2(g) = Fe(l) + H_2O(g)$; $FeO + CO(g) = Fe(l) + CO_2(g)$; $FeO(l_2\ sat) + CO(g) = Fe(l_1\ sat) + CO_2(g)$. H. Sawamura. (*Suiyokwai-Shi*, 1954, **12**, Apr., 283–286). [In Japanese]. The equilibrium constants of the stated reactions were determined.

PRODUCTION OF STEEL

Detroit Steel Corporation Completes the Expansion of Its Portsmouth Division. C. Longenecker and H. E. Trout. (*Blast Furn. Steel Plant*, 1955, **43**, Feb., 190–216). A comprehensive account of this American integrated steelworks which produces steel strip, rod, and wire is given. The plant has two blast-furnaces of 18 ft. 10 in. and 28 ft. 6 in. hearth dia., the larger at present working alone and producing 1100 tons of iron per day on reduced wind. Four 250-ton fixed O.H. furnaces are used for normal operation.—B. G. B.

The Expansion Scheme of John Lysaght's Scunthorpe Works Ltd. W. L. James. (*J. Iron Steel Inst.*, 1955, **181**, Sept., 17–25). [This issue].

Steelmaking at Redbourn. S. R. Isaac. (*J. Iron Steel Inst.*, 1955, **181**, Sept., 44–48). [This issue].

Modern Trends in the Iron and Steel Industry. D. E. Diaz-Varela y Ceano-Vivas. (*Tec. Met.*, 1954, **10**, Sept.-Oct., 241–258). [In Spanish]. A detailed survey of iron and steelmaking techniques, with particular reference to modern developments, is presented, including a description of continuous-casting processes and methods for the manufacture of sponge-iron.

On the Side-blown Baby-Bessemer Process in U.S.S.R. and Chinese Communist Region. M. Fukushima. (*Tetsu to Hagane*, 1954, **40**, Dec., 1128–1142). [In Japanese]. A review is given of recent Russian experience in the use of small side-blown converters for producing ingot steel. Superheated low-silicon molten pig is blown; this is produced in special cupolas containing 90–95% of scrap, and partially recarburized. A steel of lower gas content and higher resistance to hot-shortness compared with O.H. steel is claimed. In China, comparatively low-Si irons are being blown in this way.

Improvements in Checker Cleaning during Operation. W. H. Friesell. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1954, **37**, 156–164). Recent improvements in the procedure for checker cleaning at the Homestead plant of United States Steel Co. are discussed. These include partial re-design of the system, and lancing with compressed air, steam, or high-pressure water.—G. F.

Double-pass versus Single-pass Checkers. F. G. Jaicks. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1954, **37**, 172–179). A comparison of double-pass and conventional single-pass checkers has been made on identical furnaces at the Indiana Harbor Works of Inland Steel Co. The design of the two systems is described, and the campaign lives, fuel consumptions, and other differences in performance are compared.—G. F.

Checker Cleaning. E. F. Franzen. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1954, **37**, 164–166). The Chicago plant of Republic Steel Corporation uses both compressed-air lancing and high-pressure chemical spraying for checker cleaning. Brief details of the latter method are given.—G. F.

Elimination and Control of Air Infiltration. H. M. Parker. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1954, **37**, 295–297). The author gives brief recommendations for eliminating and controlling the amount of air infiltration in O.H. furnaces. He stresses the importance of good furnace construction and recommends refractory sealing of the checker system on the outside and, where possible, on the inside.—G. F.

Wear of Checker Chambers and Characteristic Formulae for the Productivities of Open-Hearth Furnaces. H. Hashimoto. (*Sumitomo Metals*, 1953, **5**, Oct., 198–205). [In Japanese]. Decreases in productivity result mainly from the wear of the checker chambers, caused by corrosion and deposition of basic material from the melting chamber. Since the amount of arry-over is proportional to the production, formulæ may be derived for planning production, comparing furnaces, and improving productivity.—K. E. J.

Increasing the Life of Cooling Pipes in an Open-Hearth Furnace. W. Krause and W. Rosner. (*Hutnik*, 1954, **21**, (12),

390–395). [In Polish]. Investigations of burned cooling pipes are reported and the mechanism and causes of failure are described.—V. G.

Hot Repair or a New Roof. E. R. Eaton. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1954, **37**, 126–128). The author gives a brief description of current practice and the scheduling of O.H. furnace roof repairs at the Sparrows Point plant of Bethlehem Steel Co. A furnace requires on average four roof patches during a campaign.—G. F.

Hot Repair versus New Roof Installation. P. W. Nutting. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1954, **37**, 123–125). At Indiana Harbor Works of Inland Steel Co., the substitution of a complete knuckle-to-knuckle roof set on centres for much of the hot patching formerly done on the O.H. furnaces has been beneficial to shop operation.—G. F.

Maintenance and Care of Open Hearth Furnace Bottom. J. S. Zahn. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1954, **37**, 98–107). The author discusses maintenance practice on acid O.H. furnace bottoms at the Ohio Steel Foundry Co., describing both general bottom repairs and regular bottom maintenance.—G. F.

Shop Operating for Maximum Production, Furnace Life, and Quality. R. M. Baker. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1954, **37**, 291–293). The author details an O.H. furnace working schedule designed to give maximum production whilst maintaining quality and good furnace life.

Effect of Speed in Making up Banks and Tapholes on Temperature in Furnace System. T. D. Hess. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1954, **37**, 288–290). A brief outline is given of the routine adopted at Indiana Harbor works of Youngstown Sheet and Tube Co. for furnace maintenance between heats, and an indication is given of the effect of maintenance time on heat time.—G. F.

Stocking and Charging. E. E. McGinley. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1954, **37**, 265–273). The author reviews some of the factors which are important in reducing tap-to-tap times, referring particularly to the Homestead Works of United States Steel Corp. The main factors dealt with are scrap preparation and charging, and firing practices.—G. F.

Effect of Quality of Scrap in the Open Hearth. A. K. Moore. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1954, **37**, 59–60). Results are given of a series of tests at the Steel Company of Canada Ltd., showing the effects of scrap grading on yield, production, and steel quality.—G. F.

Inspection and Effect of Grades of Scrap. H. M. Parker. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1954, **37**, 58). Brief details are given of the system of scrap inspection and the effect of different grades on production and steel quality at Armco Steel Corporation's Middletown works.—G. F.

Selection and Use of Scrap. G. G. Mueller. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1954, **37**, 61–62). The author emphasizes the value of correct scrap selection and shows how far the contents of sulphur and residual elements in different grades of scrap can vary.—G. F.

Effects of Quality of Scrap. J. H. Flaherty, jun. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1954, **37**, 55–58). The author outlines a series of tests carried out at Jones and Laughlin's Pittsburgh works to determine the effects of different types of scrap on yield, production, and steel quality.—G. F.

The Behaviour of Oxygen in the Basic Open-Hearth Process. K. Morikawa, Y. Shimokawa, and T. Tanoue. (*Sumitomo Metals*, 1952, **4**, May, 299–304). [In Japanese]. Studies were made during manufacture of low-carbon (0·10–0·18% C) rimming steel. Oxygen balances of the slag and metal during melting and refining show that most of the oxygen in the slag and metal comes from the furnace atmosphere. Oxygen in the metal increases with iron oxide in the slag and slag basicity and decreases with carbon. From tapping to the end of casting, the oxygen content falls from 0·54% to 0·022%.—K. E. J.

Laboratory Studies of Pouring Conditions as Revealed by High-speed Motion Pictures. H. T. Clark. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1954, **37**, 252–255). A brief outline is given of the method adopted by the Research Dept. of Jones and Laughlin Steel Corp. to study splash during teeming. High-speed ciné-photography was used, with metal teemed into partial moulds with specially-shaped tools.—G. F.

Open Hearth Ladle Linings. J. Boullosa, jun. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1954, **37**, 314–319). The author discusses ladle lining procedure and describes the method recently adopted at the Stanley Works. Several factors of great importance to ladle lining life are listed.—G. F.

Study on the Killed Steel Ingot. K. Satoi. (*Sumitomo Metals*, 1952, **4**, July, 337–352; Oct., 397–410). [In Japanese]. In bottom pouring practice, ingot cracks are mainly caused by diagonal metal flow and residual stresses in new moulds. A special method has been devised to eliminate 'ring ghosts.' The relationship between sand marks and the erosion products on the refractory has been determined. (31 references).

Influence of Pouring Practice on Axial Soundness of Large Ingots. S. A. Ott. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1954, **37**, 107–110). In outlining the practice at Midvale Steel Co. in casting 35–82-in. ingots for rotor forgings, the author briefly discusses the effect on axial soundness of tapping temperature, ladle holding time, teeming temperature and speed, sulphur and phosphorus contents, and height/width ratio. An index based on these factors is used to determine whether an ingot should be further processed.—G. F.

Manganese and Formation of Inclusions. D. C. Hilty. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1954, **37**, 222–233). The mechanism of the formation of inclusions during the solidification of steel is discussed, and the effects of furnace practice on the mechanism is considered. The manganese modification of the Fe–S–O system and the effect of initial oxygen content on inclusion formation are discussed.

On the Solidification of Rimming Steel Ingots. Y. Shimokawa and T. Tanoue. (*Fuso Metals*, 1951, **3**, Apr., 67–77). [In Japanese]. Experimental results are presented of work on the rate of solidification, the variation of molten metal, scum and gas evolution during solidification, and the effect of C and Mn on the ingot structure and gas evolution.—K. E. J.

Fundamental Studies on the Gas Evolution During Solidification. Y. Shimokawa and T. Tanoue. (*Fuso Metals*, 1951, **3**, Apr., 61–66). [In Japanese]. Calculations of the gas expected to be evolved during solidification of alloys of the composition of rimming steel show the maximum amount for the metal having a 'balanced' equilibrium composition. The actual amount found in practice is less, indicating a relatively high gas content in the ingot.—K. E. J.

"Plancor 422"—A Wartime Steel Plant. M. E. Goetz. (*Metal Progress*, 1955, **67**, Feb., 109–115). The difficulties encountered in the design, construction, and emergency operation of an integrated plant for making gun steel or aircraft quality steel are described. The plant used molten pig iron and its own scrap by duplexing O.H. and electric furnaces and rolled large ingots into forging blooms.—B. G. B.

The Cornigliano Integrated Steelworks. R. Levi. (*Ing. Mecc.*, 1954, **3**, Nov., 41–49). [In Italian]. The author reviews the principles which have led to the integration of iron and steelworks and shows how these have been applied in the construction of the new Cornigliano steelworks.—M. D. J. B.

Engineering Conception of Fairless Works. J. D. Rollins. (*Iron Steel Eng.*, 1954, **31**, Dec., 115–118). The author discusses the reasons why the Fairless works were developed on the lines adopted. Engineering features of special interest are described.—M. D. J. B.

French Steel Making Progress in 1954. G. Husson. (*Metal Progress*, 1955, **67**, Jan., 127–128, 202, 204). The recent development of optical pyrometers for use with basic Bessemer converters and the use of oxygen in the blast have enhanced the production of steel with low sulphur, phosphorus, and nitrogen contents. The apparatus for the collection of the red fumes of iron oxide resulting from the use of oxygen in steelmaking has been successfully operated. Combustion and heat exchange in O.H. furnaces is being studied.—B. G. B.

Simultaneous Desulphurisation and Deoxidation of Steel Heats. W. A. Fischer and H. Engelbrecht. (*Stahl u. Eisen*, 1955, **75**, Jan. 27, 70–75). Swedish steel scrap (6 kg.) was heated in a crucible of 90% CaO and 10% CaF_2 in a coreless induction furnace on a CO atmosphere and treated with metallic silicon for desulphurization and deoxidation. Samples for determining the sulphur, carbon, and silicon were taken at 5-min. intervals. The constant of the deoxidation by silicon is $K_{Si(CaO)} = [\%Si] \times [\%O]^2 = 2 \cdot 3 \times 10^{-7}$, whereas the constant for processing in an acid crucible is $2 \cdot 8 \times 10^{-5}$. In the CaO–CaF_2 crucible the sulphur could be reduced to as low as 0·001%. The effect is attributed to a reaction with

the crucible material and to the very low dissociation pressure of the compounds formed compared with that of pure SiO_2.

Stop Signal for Bessemer Operation—Measurement and Recording of the True Flame Temperature of the Converter. J. Galey, P. Leroy, and M. Denis. (*Rev. Mét.*, 1954, **51**, Nov., 795–809). In the basic converter, the experience of the operator has been of prime importance in judging when to stop the blow. A more scientific method is proposed based on recording the opacity of the flame. An automatic stop signal, at a given opacity, can be applied.—G. E. D.

Conversion of Low-Phosphorus Iron in the Oxygen-Enriched Converter: Further German Investigations. (*Iron Coal Trades Rev.*, 1955, **170**, Jan. 28, 205–207). Results are given of recent German investigations in oxygen-enriched converter practice with controlled mixtures of low-phosphorus Stahleisen and 2% phosphorus basic Bessemer irons. The possibilities of early dephosphorization, the behaviour of sulphur, and the effect of manganese are discussed.—G. F.

Open World's Largest Oxygen Steel Plant. (*Canad. Metals*, 1954, **17**, Dec., 25–26). A brief account is given of the new converter for making 40 tons/hr. of steel by the downward-blowing oxygen process at Dofasco's works, Hamilton, Ontario.—R. A. R.

Use of Desiliconized Hot Metal in the Basic Open-Hearth Furnace. L. M. Billimoria, T. V. S. Ratnam, and S. N. Anant Narayan. (*Tisco*, 1955, **2**, Jan., 9–22). The authors consider the necessity for desiliconization and outline the methods by which it can be achieved. The procedure at T.I.S. Co. and some production data are presented and discussed. It is concluded that by introducing into the metal in a basic O.H. furnace oxygen in the form of solid oxides (iron ore, scale) and supplementing the balance by gaseous oxygen, the desiliconization time is greatly reduced. No difficulty is encountered in the form of fumes or splashing, as is common with ladle desiliconization.—L. E. W.

Observations on the Use of Carburite in Open-Hearth Furnaces. (*Radex Rundschau*, 1954, (4–5), 166–171). [In German and Italian]. Details are given of comparative tests in a 30-ton furnace to determine the increase in recarburizing rates when using carburite instead of steel scrap. From the data it is concluded that this procedure is often more advantageous in that the reductions in bath temperature encountered when using scrap are eliminated.—G. G. K.

Notes on the Conversion of Open-Hearth Furnaces to Oil Firing. F. Bartu. (*Radex Rundschau*, 1954, (4–5), 133–142). [In German]. After discussing the economics of oil firing in comparison with producer gas, the author examines the influence on flame properties of factors such as oil input rate, atomizing agent, excess air, and kinetic energy of the oil jet. Further points discussed are influence of oil viscosity, admixture of gas to the fuel oil, design of air ducts, suspended construction of lower furnace, and stack draught.—G. G. K.

Electrostatic Precipitation of Open-Hearth Furnace Dust. J. H. Smith. (*Blast. Furn. Steel Plant*, 1955, **43**, Jan., 58–59). Satisfactory results have been obtained at the Kaiser Steel Corporation with a Cottrell electrostatic precipitator for cleaning O.H. furnace fumes. The exit gas now contains 18 lb. of dust per hr. (0·08 grains/cu. ft.). The precipitator has not affected the performance of the furnace.—B. G. B.

Sulphur in Steelmaking Processes. R. W. Evans. (*Inst. Fuel, Inaugural Conf. at Inst. Mech. Eng.*, Oct. 6–7, 1954, 22–33). The chemistry of the basic O.H. process is discussed with an example of a slag analysis and of the refining of a 200-ton charge. The addition of sulphur to the bath by the materials charged, and by pick-up from the burner flame, is considered in detail, and the elimination of sulphur from the materials before charging is described. Methods of furnace operation to reduce the sulphur content are also discussed.

Operating Data and Observations on Natural Gas Fired Open-Hearth Furnaces. C. Stocchi. (*Met. Ital.*, 1954, **46**, Dec., 446–449). [In Italian]. Operating details are given of the 30-ton O.H. furnaces at Dalmine steelworks. Originally operated with methane, the furnaces are now worked with a combination of 75% methane and 25% oil which, although slightly more expensive, produces a luminous flame and raises furnace output.—M. D. J. B.

Physical Chemistry and Steelmaking. F. D. Richardson. (*Iron Coal Trades Rev.*, 1955, **170**, Feb. 18, 365–366). In this article the author answers recent criticism by D. J. O. Brandt of the value of fundamental physico-chemical research in steelmaking. He maintains that the amount of such research currently carried out is inadequate and that the utilization of such physico-chemical data as exist has been shown to be of value in process development. Concluding remarks by Brandt are also given.—G. F.

The Basic Open Hearth Process: (3) Practical Applications. G. R. Bashforth. (*Brit. Steelmaker*, 1955, **21**, Jan., 10–17). The author describes methods of melt and slag control and discusses their importance in both hot-metal and cold-metal basic O.H. practice. Details are then given of experience in the operation of two 90-ton tilting furnaces employed on cold-metal practice, and a brief consideration of the Bertrand-Thiel process is also given.—G. F.

Contribution to the Technology of Duplex Processes. A. Děkanovský. (*Hutnické Listy*, 1955, **10**, (3), 140–144). [In Czech]. Several duplex and semi-duplex processes of steelmaking are reviewed from the point of view of maximum efficiency in relation to present-day Czechoslovak requirements and raw-material supplies. The converter used in conjunction with the O.H. furnace is shown to give the best combination.—P. F.

The Hot-Blast Cupola in the Steel Works. T. Kootz and H. Rellermeyer. (*Arch. Eisenhüttenwesen*, 1955, **26**, Jan., 1–8). Time for charging and melting-down in the O.H. furnace would be reduced markedly if molten iron low in carbon is charged. A cupola operated with blast-furnace blast and having an output of 8 tons/hr. was used for the trials. The temperature of the blast varied between 460° and 710° C. The lowest carbon content obtained was about 2%. Temperature and coke ratio both had a marked effect on the final carbon content. Increasing the blast velocity decreased the carbon. Desulphurization became more difficult with decreasing carbon. The authors suggest blowing the iron in a converter before charging into the O.H. furnace in order to reduce the carbon to the desired value.—T. G.

Interest in Using Low-Carbon Pig Iron made in the Hot-Blast Cupola in the Open-Hearth Furnace. Boutigny and Barbazanges. (*Centre Doc. Sid., Circ. Inf. Tech.*, 1955, **12**, (1), 169–192). The benefits from using low-carbon pig iron in the O.H. furnace charge are explained. Operation of a hot-blast cupola is described, and the advantages outlined, with illustrated examples of a plant. Operating data from furnaces charged with cold pig iron, Thomas iron, or hot low-carbon pig iron, are compared. Average operation of five 80-ton furnaces showed a production from one furnace of 57,000, 60,000, and 73,000 tons/year, respectively, with each type of charge. It is emphasized that the capital cost of the hot-blast cupola is less than that of the equivalent additional O.H. capacity.—T. E. D.

Electric Furnaces in the Steel Industry. (*Brit. Engineering*, 1955, **37**, Feb., 284–286). Details are given of two types of special electric furnace produced by G.W.B. Furnaces, Ltd. One is a lift-off type furnace for batch softening at 780–800° C. of coiled stainless strip, with forced convection to ensure uniform conditions. Another furnace for production of steel castings, rated at 2000 kVA., melts a 3-ton charge in 2·16 hr. and incorporates an improved system of hydraulic electrode regulation.—K. E. J.

Sulphur Removal Studies in Basic Electric Furnace Melting. E. A. Loria. (*Blast Furn. Steel Plant*, 1955, **43**, Jan., 86–87, 114–115). Factors affecting the removal of sulphur during electric steelmaking are considered. A strongly basic slag is required and methods of adding lime during the course of the heat are explained. Injection of powdered lime with nitrogen or air instead of simply shovelling on to the slag has been found satisfactory in several instances.—B. G. B.

Enriching Basic Slag with Apatite. O. Engel. (*Hutnické Listy*, 1955, **10**, (2), 82–85). [In Czech]. It is shown, on the basis of experiments, that the P_2O_5 content of basic converter slag can be increased, provided that the SiO_2/P_2O_5 ratio is maintained constant at 0·42, by the addition of sand–apatite mixtures. The CaO content is maintained at 48%; the P_2O_5 content can be increased up to 19%; higher proportions are unattainable without violation of the relative ratios in the proportions of other constituents.—P. F.

Measurement of the Electromotive Forces at 1500° C. and X-Ray Studies of the System Ferrous-Oxide/Aluminium-Oxide. W. A. Fischer and A. Hoffmann. (*Arch. Eisenhüttenwesen*, 1955, **26**, Jan., 43–50). Potential determinations and X-ray back-reflection studies of the system $FeO–Al_2O_3$ were carried to establish the equilibrium diagram at 1500° C. The e.m.f. curve shows the following values: in 0–1·5% FeO,

120 mV.; 1·5–48·8% FeO, an increase to 173 mV.; between 48·8% and 50% FeO, a jump to 270 mV. This value is maintained up to 63% FeO. From the X-ray back-reflection photographs at 1500° C. the structure was established as a spinel $FeO.Al_2O_3$ which is stable at 1500° C. The lattice constants are between 8·134 and 8·177 ± 0.002 Å.—T. G.

The Present State of Development of Work on the Structure of Cast Silicates. J. O'M. Bockris and J. D. Mackenzie. (*Rev. Mét.*, 1954, **51**, Sept., 658–664). Previous work on cast silicate structures was limited by their complexity and their high melting points. Using a molybdenum tube furnace, conductivities and viscosities have been determined up to 2300° C. and, where necessary, down to a pressure of 0·1 mm. Hg. The ionic nature of their structure is established since silicate melts, at least up to the orthosilicate, are found to obey Faraday's laws.—G. E. D.

Testing Steel Plant Lime: Method Developed in East Germany. R. Sewell. (*Brit. Steelmaker*, 1955, **21**, Feb., 46–48). An account is given of efforts recently made in East Germany to develop a rapid and simple test for evaluating steelworks lime. A definite relationship is shown between reactivity of the lime in the metallurgical process and its hydraulic reactivity.—G. F.

Study of Ingot Moulds in Thomas Steelworks. J. Duflot. (*Publ. Inst. Rech. Sid.*, Série **A**, 1954, (74), Sept., 156 pp.). This comprehensive treatise covers work by French and foreign investigators. Design of ingot moulds, analysis and properties of the iron used for the moulds, and the mode of manufacture are considered. Conditions under which moulds are used, faults that occur, and reasons for rejecting moulds are examined, and types of mould bases are discussed. Possible lines for future research are suggested. (96 references).—T. E. D.

The Colville-Hamilton Ladle Metal Depth Indicator. A. M. Hamilton. (*West Scotland Iron Steel Inst.*, Paper No. 478, Feb. 18, 1955). The author describes and illustrates the development and construction of an indicator for determining the depth of metal left in a ladle. The instrument consists essentially of a contact member with one electrode 3 in. higher than the other, so that below a certain level the electric circuit is broken or the difference of electrical resistance between molten metal and slag is indicated. An instrument based on the sextant and used for estimating the amount of metal poured into a standard ingot mould is also briefly described.—L. E. W.

Horizontal Pouring. V. Ferrari and D. Bellini. (*Met. Ital.*, 1954, **46**, Nov., 417–420). [In Italian]. Experiments and the results obtained in the horizontal pouring of ingots are described. These indicated that horizontal pouring is quite practicable and that this procedure should have considerable technical and economical advantages.—M. D. J. B.

Production-Scale Vacuum Casting of Steel. (*Iron Coal Trades Rev.*, 1955, **170**, Feb. 4, 246–248). The problem of hydrogen embrittlement of high-grade alloy steels has led to the adoption of vacuum-casting on a production scale at the Bochumer Verein works. The steel may be de-gassed in the ladle and cast under ordinary atmospheric conditions, or the entire ingot up to 150 tons in weight may be cast under vacuum.—G. F.

Electric Ingot Process for Alloy Steel Production. (*Engineer*, 1954, **198**, Dec. 24, 894–895). The article describes one electric process for continuous melting and casting with progressive solidification which, it is claimed, provides uniform analysis, minimum segregation, and which is particularly suitable for 'super alloys' of the type used in jet engines.—M. D. J. B.

Continuous Casting of Steel. J. S. Morton. (*South Wales Inst. Eng., Advance Copy*, Mar. 17, 1955). Conventional and continuous casting processes are compared. The development of continuous casting processes is outlined and the problems involved are discussed. The B.I.S.R.A. process is shown to be scientifically sound and technically superior to those developed by purely empirical methods. The pilot plant at the works of William Jessop and Sons Ltd., Sheffield, is described. This plant produces 2½–4-in. square billets of high-speed, stainless, and special alloy steels, which are the most difficult to cast continuously.—E. C. S.

Continuous Casting of Alloy Steel Billets. T. H. Adair. (*Canad. Min. Met. Bull.*, 1954, **47**, Nov., 740–747: *Trans. Canad. Min. Met.*, 1954, **67**, 475–485). Some of the devices developed for the continuous casting of metals are briefly described, beginning with the Bessemer machine, designed in 1842, and continuing with the Poland-Lindner, Williams, Ennor, and Junghans machines. The Rossi-Junghans machine, recently installed at Atlas Steels Limited, Welland, Ont., by Freyn Engineering of Chicago, is described in some detail.—T. E. D.

Study on Ingot-Making Practice (IV). S. Maekawa and Y. Nakagawa. (*Tetsu to Hagane*, 1954, **40**, Dec., 1110–1115). [In Japanese]. Studies were made on killed low-carbon Cr–Mo steel ingots melted in the Héroult furnace. In an ingot deoxidized with Mn and Si in the furnace, large sand at the outside of the ingot had been included before casting, but the sand content was greater inside, owing to the production of fine spherical SiO_2 during solidification. In an ingot treated similarly but with Al added in the ladle, the sand content was at a maximum at the outside, being mainly Al_2O_3 produced in the ladle.—K. E. J.

An Improvement in Hot-Top Design for Killed Steels. A. M. Hamilton. (*West of Scotland Iron Steel Inst.*, Paper No. 479, Feb. 18, 1955). A slight modification to increase the yield in killed steel ingots is described. An ordinary hot-top casting is used and the required taper obtained by filling in with brickwork. The surface of the metal after filling is at once covered with a good anti-piping compound. This should give a **U**-shaped pipe with a horizontal bottom and an extra yield of up to 5% on 10–30-ton ingots.—L. E. W.

Heterogeneity and Segregation: I. Heterogeneity and Segregation in Fully-Killed Steels for High-Duty Forgings; II. Formation and Causes of Segregation in Fully-Killed Steel Ingots; III. Influence and Distribution of Elements in Steel Ingots; IV. Segregation of Inclusions and Shrinkage in Steel Ingots; V. Rate of Solidification of Fully-Killed Steel Ingots; VI. Directional Solidification of Steel Ingots. K. G. Lewis. (*Iron Coal Trades Rev.*, 1955, **170**, Jan. 21, 125–132; Jan. 28, 189–196; Feb. 4, 251–256; Feb. 11, 309–314; Feb. 18, 381–387; Feb. 25, 437–442). Stressing that segregation problems arise from the first moment of solidification, the author examines in Part 1 the factors governing the elementary process, viz. nucleation, undercooling, and latent heat of transformation. The mode of crystallization in the chill, columnar, and central zones is discussed, and selective freezing is described. In Part 2 the occurrence of general segregations is discussed, and the mechanism theories of various investigators are considered. The mechanism of pipe formation is also described and the factors influencing its shape are discussed. Part 3 deals with the physico-metallurgical factors governing solidification, and consideration is given to the influence of various elements, including phosphorus, sulphur, and the common alloying elements, on the segregation occurring in an ingot. In Part 4, the distribution of inclusions, particularly sulphides and silicates, in the different zones is first considered, followed by data on volume changes during solidification and on factors affecting shrinkage, including air-gap formations. Part 5 deals with methods of investigating rates of solidification, reviews being given of mathematical analysis, pour-out tests, thermocouple methods, and recent analogue techniques. The effects of superheat and under-cooling are also discussed. Directional solidification is discussed in Part 6, and the extent to which dissolved gases and pouring technique influence solidification is indicated. Data on the effect of mould size and shape on segregation are also given. (197 references).—G. F.

Promises and Problems Posed by Vacuum Melting. J. H. Moore. (*Amer. Inst. Min. Met. Eng. Elec. Furn. Steel Conf.*, 1954: *J. Met.*, 1954, **6**, Dec., 1368–1369). The author compares the impact and high-temperature properties, and fatigue and service test data of steels and nickel-base alloys produced both by vacuum melting and melting in air. The superiority of the vacuum-melted material is due to increased freedom from inclusions, elimination of gaseous or gas-metal compound precipitation, and better composition control. Economic and technical problems are outlined.—G. F.

Bright Future Predicted for Vacuum Melted Metals in Chemical Industry. E. M. Mahla. (*Amer. Inst. Min. Met. Eng. Elec. Furn. Steel Conf.*, 1954: *J. Met.*, 1954, **6**, Dec., 1370–1371). The author considers that vacuum-melted metals will be of pronounced benefit to the chemical industry in three main fields of interest, associated with the essentially inclusion-free surface of these materials. Pit corrosion resistance is likely to be greatly improved, and the higher transverse fatigue

properties and high quality surface are of value for high-pressure equipment and film-casting wheels respectively.—G. F.

FOUNDRY PRACTICE

Modern Methods Employed in Berliet Foundries of France. V. Delport. (*Foundry*, 1954, **82**, Dec., 90–93, 242). The equipment and methods used in the iron and steel foundries of S.A. Automobiles M. Berliet at Venissieux, Lyon, France, are briefly described.—B. C. W.

What Does a Casting Cost? U. F. Von Rosen. (*Foundry*, 1955, **83**, Jan., 84–86, 140, 142). A brief description is given of the costing procedures recommended by the Non-Ferrous Founders Society for use in small foundries.—B. C. W.

Foundry Hygiene Problems. H. J. Weber. (*Trans. Amer. Found. Soc.*, 1954, **62**, 214–218). The toxicity and maximum allowable concentrations of 20 materials which are used or may occur in foundries are discussed, together with the remedial measures that are required to avoid any danger to health.—B. C. W.

On Systems for Grouping the Cast Irons. A. Wittmoser. (*Giesserei*, 1954, **41**, Dec. 23, 685–692). The nomenclature and systematic arrangement of cast irons is first discussed in general terms. A review is given of the development of malleable and grey cast iron. A diagram in which all types of cast iron, in particular the spheroidal graphite irons, are classified is developed.—R. J. W.

Relationship of Carbon Equipment to the Properties of Cast Iron. W. C. Jeffery, E. E. Langner jun., W. G. Mitchell, and G. D. Azizi. (*Trans. Amer. Found. Soc.*, 1954, **62**, 568–578). The physical and mechanical properties of a large number of heats of cast iron are correlated with the carbon equivalent (defined as $\%\ TC + 0{\cdot}3\ (\%\ \mathrm{Si} + \%\ \mathrm{P})$, where TC is the total carbon content). It is concluded that the carbon equivalent correlates sufficiently well with the major properties of cast iron to be used in foundry work as an approximate formula for estimating these properties from the chemical analysis.

Foundry Quality Control. A. P. Deacon. (*Canad. Metals*, 1954, **17**, Sept., 30–34; Oct., 29–32). Methods used to control casting defects are considered. These include the use of control charts on which operating data are recorded. One of the charts is designed for cupola operation; it eliminates the need for arithmetical accuracy on the part of the operator.

Automation Unit Performs All Operations in Casting of Small Parts. L. F. Miller. (*Iron Age*, 1954, **174**, Nov. 4, 128–130). A fully automatic system has been installed in the malleable-iron foundry of the Eberhard Mfg. Co., Cleveland, for producing up to 300 multiple cavity moulds per hour, and casting in the weight range 1 oz. to 2½ lb. The unit performs the operations of moulding, closing, clamping, cooling, stripping, and shaking out. Floor area is a quarter of that for conventional layouts.—D. L. C. P.

Mechanical Handling in the Foundry. J. Pascal. (*Mét. Constr. Mécan.*, 1954, **86**, Dec., 917–923; 1955, **87**, Jan., 23–27). The need for increased mechanical handling in the foundry is explained. Examples of suitable equipment and of the results obtained by increased mechanization are given.

Cracks in Large Iron Castings. H. Rieger. (*Giessereitechnik*, 1955, **1**, Jan., 4–9). The various reasons why cracks may appear in large iron castings are illustrated and discussed. L. J. L.

Automation Within Reach of Many Foundries. W. E. Dougherty. (*Iron Age*, 1954, **174**, Oct. 21, 224–227). The requirements for establishing a highly automatic foundry are considered. Methods for dealing with a variety of work on a standardized line and a suitable sand control are necessary.

Closed-Top Cupolas End Air Contamination. R. H. Herrmann. (*Foundry*, 1954, **82**, Dec., 86–89). The hot-blast sealed cupolas installed at Ford Motor Co. Dearborn Iron Foundry in Dearborn, Mich., are briefly described together with the associated dust-collection system. The cupola exhaust gases pass through a combustion chamber, heat exchanger, wet dust scrubber, and centrifugal type exhauster. The system functions automatically, continuously compensating for operating variables.—B. C. W.

Coke Classification by Cupola Furnace Experiments. H. Jungbluth. (*Giesserei*, 1955, **42**, Jan. 6, 2–6). The concept of the coke evaluation number is first introduced. The connection between melting efficiency, coke additions, the amount of air, and the combustion ratio is given and illustrated graphically. Methods to determine the "reactability" of coke are described. The mechanism whereby the temperature of the iron is increased by larger additions of coke, with constant amounts of air, is discussed.—R. J. W.

The Frauenknecht Furnace. G. Speer. (*Giessereitechnik*, 1955, **1**, Feb., 18–20). The furnace is a modified cupola furnace. It requires no special attention, because it is self-regulating. Blast pressure is low and furnace lining durable; carbon content can be controlled by hot blast, and the scrap charge can be large. Comparative tests have shown that the furnace is capable of producing better castings using less fuel than a cupola of the same size. The average sulphur content is about 0·08%.—L. J. L.

Importance of Slag Control in Acid Cupola Operation. E. A. Loria. (*Foundry*, 1955, **83**, Feb., 84–87, 240, 242–245). The fundamentals of slag–metal reactions as applied to acid cupola melting are discussed. Among the aspects considered are slag fluidity and basicity, the effect of iron oxide in the slag on the oxygen content of the metal, and desulphurization of the iron.—B. C. W.

Operating Practice with the Basic-Lined Cupola. C. Greenlee. (*Foundry*, 1955, **83**, Feb., 88–91, 184, 186, 188, 190). The advantages of basic-lined cupolas are outlined and the operation of such cupolas is discussed. Among the aspects considered are basic cupola slags, the lining of a basic cupola, control factors, lining erosion, tapping temperatures, and calcium carbide additions.—B. C. W.

Cupola Gas Scrubbers. O. J. Brechtelsbauer. (*Trans. Amer. Found. Soc.*, 1954, **62**, 420–424). The cupola gas scrubbers installed at the Chevrolet Saginaw Grey Iron Foundry, Saginaw, Mich., are described and their operation discussed. The installation has a single spray mounted above the apex of a cone, the hot gases passing between the cone and a shroud. Results of cupola emission tests are included.—B. C. W.

The Collection of Cupola Dust. F. M. Shaw. (*Brit. C.I. Res. Assoc., J. Res. Dev.*, 1955, **5**, Feb., 563–592). Methods used to collect cupola dust are described. The baffle and water-spray systems are considered to be the most economical means of obtaining a good degree of gas cleaning.—B. G. B.

The Comparison Between the Growth of the Spheroidal Cast Iron made by Calcium Addition and that of some other Cast Irons. T. Kusakawa. (*Tetsu to Hagane*, 1955, **41**, Feb., 111–115). [In Japanese]. Tests by repeated heating between 600° and 900° C. were made with spheroidal graphite cast iron produced by additions of Ca, Mg, or Ni and flaky iron. With good spheroidal structures growth hardly occurred, while mixed structures gave appreciable growth. With Si contents >3% a ferrite-type structure was found.—K. E. J.

Some Observations on the Ductility of Ferritic Nodular Iron. G. N. J. Gilbert. (*Brit. C.I. Res. Assoc., J. Res. Dev.*, 1954, **5**, Dec., 470–472). Nodular iron, unlike steel, does not show a yield and it is incorrect to quote a yield stress for this material. The author suggests that the proof stress should be quoted instead. Elongation at maximum load, which indicates the ability of a material to deform without developing a crack, affords a better criterion than the total elongation at failure by which to compare the ductility of ferritic nodular irons and steels.—B. G. B.

Graphitization of Magnesium-Treated White Irons. C. M. Hammond, F. J. Walls, W. B. Pierce, and R. A. Flinn. (*Trans. Amer. Found. Soc.*, 1954, **62**, 385–388). Results are presented on the graphitization of magnesium-treated white irons between 870° and 1100° C. It was found that spheroidal graphite could be obtained by short-time treatments at 1040–1100° C. and that the time required for graphitization at a given temperature increased with section size. The results also indicate that white or partly graphitized magnesium-treated irons could be rapidly annealed by treatment in molten salt or by induction heating.—B. C. W.

Spheroidal Graphite Cast Iron as Material for Mechanical-, Thermal- and Chemical- (MTC) Tested Castings. H. Timmerbeil. (*Giesserei*, 1955, **42**, Jan. 6, 7–15). Spheroidal graphite cast iron is considered as a new type of material and the damping capacity compared with other cast materials. Further possible developments, and the effect of increasing the surface hardness with flames to produce increased weldability are considered. The temperature stability of alloyed cast iron with spheroidal graphite is described, in particular those alloys containing up to 7% of silicon. The variation of Brinell hardness and carbon content after different heat-treatments is given, with the strength properties at high temperatures.—R. J. W.

Does Spheroidal Graphite Grey Iron Form a Separate Class of Material? P. A. Heller. (*Giesserei*, 1955, **52**, Jan. 6, 15). It has previously been shown that the properties of grey cast iron with seam graphite depend upon (*a*) the Brinell hardness of the metallic matrix, (*b*) the elastic modulus and the amount and distribution of graphite, and (*c*) the tensile strength of the matrix and also the crystallization of graphite. This short note compares experimental results with values of elastic modulus calculated from the equation (Brinell hardness) × (Young's modulus)=(tensile strength)$\times 10^5$. The calculated results are about 3·5% high for grey cast iron. Similar results are tabulated for spheroidal graphite grey castings and different equations compared.—R. J. W.

The Effects of Furnace Atmospheres on the Annealing of Black-heart Malleable Iron—A Critical Review. J. E. Rehder. (*Trans. Amer. Found. Soc.*, 1954, **62**, 138–142). A critical review is given of the literature on the effects of furnace atmospheres on the rate of annealing of black-heart malleable iron. Both laboratory investigations and commercial experiences are covered.—B. C. W.

Graphitization of Rims in Malleable Iron. H. A. Schwartz and J. D. Hedberg. (*Trans. Amer. Found. Soc.*, 1954, **62**, 282–285). The graphitization of the surface of a white-iron casting was studied and it was found that in the outer 0·1 in. the process was different from that in the centre and was slower; the outer 0·02 in. layer was particularly slow in graphitizing. The reasons for this are discussed.—B. C. W.

The Graphitization of White-Heart Malleable Iron Castings, With Particular Reference to the Sulphur and Manganese Contents. W. Oelsen, K. Roesh, and E. Wendel. (*Giesserei Technisch-Wissenchaftliche Beihefte*, 1954, Dec., (14), 735–744). Laboratory experiments and results are described in which the effect of aluminium, aluminium sulphide, chromium, manganese, iron sulphide, and manganese sulphide on the graphitization of white-heart malleable iron castings has been examined—R. J. W.

High Permeability Steel Castings. Design and Manufacturing Techniques. J. F. Hinsley. (*Elect. Rev.*, 1955, **156**, Feb. 11, 203–206). Principles affecting casting design are discussed in the production of high-permeability steels, concluding with a brief reference to 'non-magnetic' or low-permeability steels. The use of fillets in the reduction of magnetic flux density and examination of castings by non-destructive testing is treated briefly.—L. D. H.

Further Development of the Use of Exothermic Riser Additions for Steel Castings. F. Dubielzig and H. Kühne. (*Giessereitechnik*, 1955, **1**, Feb., 13–15). Recent improvements in the method are described. Examples are given to demonstrate the reduction in the weight of risers that can be obtained, with a diagram showing minimum and maximum weight of risers expressed as percentages of total weight of castings.—L. J. L.

The Layer Method, an Auxiliary Means for Determining the Method of Casting and the Casting Speed for Steel. S. Forslund. (*Giesserei*, 1955, **42**, Feb. 17, 73–81). The layer method for the determination of casting speeds for steel, and the processes involved in the formation of folds (cold casting) and the requirements for the critical minimum speed of casting, are described. A comparison is made between casting from a teeming ladle and casting over the lip. The advantages of the method are enumerated. The method has so far been used only for steel, but it has possibilities for other cast alloys.

New Standard for Steel Castings. (*Steel*, 1954, **135**, Oct. 4, 112–113). A code has been published by the Steel Founders' Society of America, recommending a minimum standard of treatment, properties, and testing for commercial carbon-steel castings; the main points of the code are presented.

A Dielectric Heating and Test Unit for the Study of Sand Properties at Elevated Temperatures. R. Rew and R. G. Godding. (*J. Sci. Instruments*, 1955, **32**, Mar., 93–95). To obtain rapid and uniform heating of foundry sand cylindrical test specimens (2 in. × 2 in.) a dielectric heater operating at 100 Mc/s has been constructed. The specimen can be heated to 1000° C. in approximately 1 min., temperature being measured by a thermocouple. The heater is used in conjunction with a testing machine, the construction of which is described, for the measurement of stress/strain curves.

Measurement of the Moisture Content of Sand. R. G. Godding. (*Brit. C. I. Res. Assoc., J. Res. Dev.*, 1954, **5**, Dec., 473–480). A method of obtaining the moisture content of sand by measuring its capacitance is described. The result is dependent on the packing density as well as the moisture content, but is not affected by small changes in the amounts of coal dust, clay, or tramp iron.—B. G. B.

The Effect of Dead Clay on the Properties of Clay-Bonded Sand. W. B. Parkes and A. G. Sealey. (*Brit. C. I. Res. Assoc., J. Res. Dev.*, 1955, **5**, Feb., 555–562). When metal is poured in a clay-bonded sand mould the sand near the mould face is heated to temperatures at which the clay loses its combined water and is said to become dead. This paper reports an investigation of the effect of increasing amounts of dead clay on the properties of moulding sand and shows how an excessive build-up of dead clay can be detected by means of standard routine tests for moisture content, green strength, and shatter index. Some indication of methods of controlling dead clay and neutralizing its effect is given.—B. G. B.

On the Influence of Foundry Sands on the Final Casting. H. Derlon. (*Giesserei*, 1955, **42**, Feb. 3, 55–57). The requirements of the casting mould are first listed and the factors affecting these requirements discussed. The causes of scabbing and other faults in the final casting are described with particular reference to the type of sand used. Gas permeability of the mould and penetration of metal into the sand are also considered, with particular reference to American researches in this field. Favourable grain structure and fire proofing of the sand play an important role in the production of castings.—R. J. W.

Casting Defects and Their Causes. Parts VI and VII. Mould Wall Analysis. (*Gjuteriet*, 1955, **45**, Jan., 1–5; Feb., 17–21). [In Swedish]. Part of the analysis of casting defects drawn up by a committee of Sveriges Mekanförbund. Eighteen different properties of the mould surface, their causes, and their effects on the finished casting are considered.—G. G. K.

Thirteenth Annual Report on Investigation of Properties of Steel Foundry Sands at Elevated Temperatures. R. G. Thorpe, O. P. Eberlein, R. C. Waugh, and P. E. Kyle. (*Trans. Amer. Found. Soc.*, 1954, **62**, 43–47). Data on the stress/strain and expansion characteristics at elevated temperatures of 18 synthetic steel foundry sand mixtures are presented and discussed, together with the scabbing tendencies of the mixtures. Results of short-time hot compressive strength tests and shock heating tests are given as well as some of the room-temperature properties of the sands.—B. C. W.

Polystyrene Patterns. (*Aircraft Prod.*, 1955, **17**, Jan., 42–44). The use of Polystyrene (Lustrex general purpose [B.S. 1493] grade produced by Monsanto Plastics Ltd.) as an alternative to wax in investment casting is described. The polystyrene pattern is made by injection moulding, and is more robust than wax. Pattern assembly with adhesives is described.—T. E. D.

Risering of Gray Iron Castings. W. A. Schmidt, E. Sullivan, and H. F. Taylor. (*Trans. Amer. Found. Soc.*, 1954, **62**, 70–77). In this fifth progress report an apparatus which enables direct shrinkage measurements to be made on solidifying iron by means of a graphite float in an externally heated riser is described, and results obtained with it are presented and discussed. The results show that most normal grey irons shrink and that the total measured shrinkage is generally less than the theoretical value. Certain green sand moulds were found to contribute to erratic shrinkage behaviour.—B. C. W.

Maximum Feeding Distance. H. A. Schwartz. (*Trans. Amer. Found. Soc.*, 1954, **62**, 556). It is shown that data obtained by Pellini and co-workers (*Trans. Amer. Found. Soc.*, 1950, **58**, 185, and *Ibid.*, 1951, **59**, 171) on the maximum feeding distance in plates and bars can be represented by the empirical equation $D = 5{\cdot}61T^{0{\cdot}53}$, where D is the maximum feeding distance and T the thickness of the casting.—B. C. W.

Grey Iron Casting with Exothermic Feeding. V. Grice. (*Canad. Metals*, 1954, **17**, Nov., 34–40; Dec., 30–32). A description is given of the application of the exothermic feeding technique. A sleeve of special chemical paste is built in around the feeder, and during casting, the sleeve is ignited by the heat of the metal. An exothermic reaction takes place which actually increases the temperature of the metal.

Dielectric Drying of Cores. K. Wirta. (*Giesserei*, 1955, **42**, Feb. 3, 49–54). The principles of dielectric drying of cores with high frequencies are first described and followed by a description of the furnace used for dielectric drying, together with the H.F. generator. Core mixtures with different contents of resin, strength binder, and water were investigated in the laboratory and the influence of different

*p*H values and mixing times studied. The bending and compressive strength and the gas permeability of the cores were compared. Works' trials are then described in a Swedish furnace with a throughput of 500 kg./hr., which showed that dielectric core drying is markedly cheaper than drying by gas-heating.—R. J. W.

Hardening Moulds and Cores by Carbon Dioxide Gas. The Practice of Ariston Alloys, Ltd., Croydon. (*Machinery*, 1955, **86**, Feb. 18, 359–362). The rapid hardening of moulds and cores made from a mixture of dry silica sand and sodium silicate, by passing CO_2 gas through the moulding core box is discussed. Moulds and cores made by this technique are claimed to be superior to those made with oil binders and with some types of resin binders.—M. A. K.

A Contribution to the Waterglass–Carbon-Dioxide Moulding Process for Grey Iron. O. Gerstmann and E. Grohmann. (*Giesserei Technik*, 1955, **1**, Feb., 16–17). A general introduction to the carbon dioxide process is presented. The basic materials are quartzitic sand and waterglass, to which 'loosening agents' such as coal dust must be added to prevent excessive caking after casting. Mixing time must not exceed 3 min.—L. J. L.

Mechanised Casting of Grey Irons into Chill Moulds. J. Vebr and K. Mlčoch. (*Slévárenství*, 1955, **3**, (1), 6–9). [In Czech]. An automatic rotary casting machine, and the associated moulds, as well as heat-treatment of castings, are described.

The Problem of Internal Stresses and Their Reduction in Centrifugally-Cast Iron Tubes for High Pressure. H. Bühler. (*Giesserei Technisch-Wissenschaftliche Beihefte*, 1954, Dec., (14), 731–733). The method of measuring internal stress systems by lathe-turning, using electrical strain gauges, is first described. The longitudinal, tangential, and radial stresses were measured in different zones of the tube and the results are presented graphically. The reduction and removal of the internal stresses by annealing for different times at 920° C. are described as is the effect of annealing at temperatures between 150° and 550° C.—R. J. W.

Some Experiences with the Statistical Analysis of Production Processes in a Grey Cast Iron Foundry. A. Zaludová. (*Slévárenství*, 1954, **2**, (12), 358–366). [In Czech]. A statistical analysis of operations in casting six-cylinder car engines disclosed that rejects resulted mainly from the non-adherence to prescribed schedules, i.e. in making core mixtures, core-drying, pouring temperature, etc. Permanent statistical quality control resulted in a decline of the reject rate.—P. F.

The Welding Phenomena between Solid Steel and Molten Cast Iron. T. Muraki. (*Waseda Univ., Rep. Castings Res. Lab.*, 1954, (5), 34–38). [In English]. Welding between solid and molten metals depends on thermal and chemical (surface) conditions; the latter were held constant during the tests, when four bars of soft steel, of different diameters, were fixed in a dry mould, and molten iron was introduced. The important thermal factor was found to be, not the high thermal capacity or temperature of the molten metal, but the time during which it remains liquid.—K. E. J.

A Typical Problem in Foundry Operation: Determine the Amount of Alloy or Inoculant Required for Specified Properties of Cupola Iron. L. W. Czarnecki. (*General Motors Eng. J.*, 1954, **1**, July-Aug., 47–48; Sept.-Oct., 59–60). A problem on the calculation of ladle additions to cupola iron is presented, and methods of calculating the required amounts of additions of known composition and recovery are demonstrated.—J. E. J.

High-Temperature Melting and Pouring of Gray-Iron Castings. II. I. Iitaka and K. Sekiguchi. (*Waseda Univ., Rep. Castings Res. Lab.*, 1954, (5), 1–3). [In English]. Results of previous work on hardness, shrinkage, etc., are confirmed. External shrinkage increases with rise of pouring temperature above 1300° C., and porosity decreases, becoming zero at 1450–1490° C. Specific weight increases with pouring temperature. The evolution of gases (N_2, CO_2, and CO) on solidification shows a marked peak when pouring temperature is 1400° C.—K. E. J.

Study on Heat-Resisting Cast Irons. N. Shinohara. (*Tetsu to Hagane*, 1955, **41**, Feb., 116–123). [In Japanese]. Results are given for the mechanical and high-temperature properties, growth, scaling characteristics, and changes in microstructure on heating to 900° C. of 22 cast irons ranging from low-Si through high-Si to high-Al irons, containing small amounts of Cr, Mo, Al, and Cu.—K. E. J.

How the Addition of Metals Affects Sulphurization-resistant Property of Cast Iron at High Temperature. M. Shiozawa and H. Nakai. (*Waseda Univ., Rep. Castings Res. Lab.*, 1954, (5), 11–13). [In English]. Studies were made with a view to increasing the resistance of cast iron to sulphur-containing compounds in the chemical industry. Aluminium additions gave the best results, followed by manganese, molybdenum, and silicon. Qualitative results of investigations on the sulphurized layers are presented.—K. E. J.

Chromizing of Spheroidal Graphite Cast Iron. S. Ueda. (*Waseda Univ., Rep. Castings Res. Lab.*, 1954, (5), 39–41). [In English]. Nodular cast iron can be chromized by the chromium chloride process, suitable conditions being 1000° C. for 5 hr., with a gas velocity of 50 c.c./min. The wear loss under test is half that of untreated iron and two-thirds that of iron electroplated with chromium.—K. E. J.

The Effect of the Lowering of Melting Point of Sand Mould on the Surface of Casting. K. Suzuki and H. Yamaoka. (*Fuso Metals*, 1951, **3**, July, 162–173). [In Japanese]. Steel castings with improved finishes may be produced in moulds where the surface has been modified; the degree of refractoriness is lowered and a more 'glassy' surface is produced. Various fluxes were examined, but further work is needed on types of flux and the amount and grain size of the moulding sand.

Perforated Pattern Plates for Rapid Exchange of Patterns. R. Chudzikiewicz. (*Przeglad Odlewnictwa*, 1954, **4**, (12), 341–348). [In Polish]. The use of machine moulding for the production of single objects and small series is discussed. Perforated pattern plates and methods of assembling patterns and gating systems to perforated plates are described.—V. G.

Research on the Graphite Mould. II. S. Terai. (*Fuso Metals*, 1950, **2**, July, 150–155). [In Japanese]. The thermal properties of graphite block moulds machined from electrodes were ascertained, and compared with those of carbon steel and dry sand. The cooling capacity of the graphite mould is five times as great as that of dry sand, but only one-third of carbon steel.—K. E. J.

Principles of Shell Moulding Processes. J. Harpula. (*Przeglad Odlewnictwa*, 1954, **4**, (12), 349–352). [In Polish]. Theoretical basis and methods of producing shell moulds from phenol-aldehyde resins are described.—V. G.

HEATING FURNACES AND SOAKING PITS

Trends of Development in Furnaces for Rolling Mills. W. Fiedler and F. Fechter. (*Radex Rundschau*, 1954, (3), Apr., 63–82). A wide survey is made of recent developments in construction and operation of furnaces in rolling mills. Consideration is given to processes of heating and heat transmission, fuels, flame technology, and furnace control. Problems of construction and materials are discussed, and the trend towards increased furnace height and division into separate zones is analysed.—E. C.

Enlargement of Rotary Hearth Furnace for Increased Production of Seamless Steel Tubes. R. E. Greenawalt. (*Indust. Heating*, 1954, **21**, Sept., 1710–1716). Brief details of the construction of the original furnace and its modified form are given.—A. D. H.

Research and Control in Hot Working Temperatures. F. Gottardi. (*Met. Ital.*, 1954, **46**, Dec., 441–445). After discussing the differences which occur between the readings of furnace temperatures and actual ingot temperatures and the resulting difficulties in rolling and forging, the author shows how optimum temperatures and permissible limits for hot working can be fixed. A temperature control technique, analogous to quality-control methods, is put forward which is designed to ensure that the desired standards are, in fact, achieved.—M. D. J. B.

Why Electric Soaking Pits Are Used. H. Drever. (*Steel*, 1954, **135**, Oct. 4, 100–102). A brief account of the construction, operation, and location of electrically heated soaking pits is given. They are being installed in more European steelworks. Average consumption is under 2 therms per net ton.—D. L. C. P.

Induction Heat. F. T. Chesnut. (*Metal Progress*, 1954, **66**, Dec., 91–94). A short description of the basic principles of the induction-heating technique is presented. Curves show the times required to heat steel bars up to 8 in. dia. to 2100° F. at the surface at 60, 1000, 3000, and 10,000 c/s.—B. G. B.

60-Cycle Induction Heating for Forging and Extrusion. J. A. Logan. (*Metal Progress*, 1954, **66**, Dec., 94–98). The advantages of low-frequency induction heating equipment are discussed. Details are given of equipment in use for the heating

of a variety of metals and alloys (including steel). One of the main advantages of this type of equipment is the low capital cost.—B. G. B.

The Case for High Frequency. F. T. Chesnut. (*Metal Progress*, 1954, **66**, Dec., 98–101). A number of examples are cited of the practical use of high frequency (> 1000 c/s) induction equipment for the heating of steel billets. It is considered that the flexibility of this method outweighs the disadvantage of the high initial cost of the frequency changers.

Dual Frequency Heating for Hot Forging. C. P. Bernhardt. (*Metal Progress*, 1954, **66**, Dec., 102–105). The advantages of using low-frequency heating equipment for heating heavy steel billets to the Curie point followed by high-frequency heating to the forging temperature are explained.—B. G. B.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

Western Electric's New Telephone Requires Advanced Heat Treating Techniques. (*Indust. Heating*, 1954, **21**, Oct., 1926–1934, 2018–2020; 1955, **22**, Jan., 74–86). The hot forming of permanent magnet rings (12% Co, 20% Mo, 68% Fe) using a specially designed forming press and the precipitation-hardening heat-treatment using induction heating are described. Equipment and methods for heat-treatment of silicon-iron laminations, the Permendur receiver armatures, Permalloy pole pieces, and the brass gongs are also described.

How to Reduce Heat Treating Costs When Using Ammonia. P. E. Peacock. (*Indust. Heating*, 1954, **21**, Oct., 1952–1958; Nov., 2234–2238). The savings by using ammonia in bulk instead of from cylinder supplies for bright-annealing stainless-steel wire are described and costs are compared.—A. D. H.

Cold Treatment Improves Accuracy, Life of V-Blocks. B. Sainati. (*Iron Age*, 1954, **174**, Oct. 14, 136–137). The Frozone Process, in which case-hardened **V**-blocks are given a 3-cycle cooling treatment to −125° F. after heat-treatment, is described.—D. L. C. P.

Large Rotary-Retort Carburizing Furnace Installation. G. K. Murray. (*Machinery*, 1954, **85**, Nov. 19, 1076–1079). Three rotary retort furnaces supplied by Birlec Ltd. for gas carburizing motor-vehicle components are described. The furnaces, when working at full rating, can handle 15 cwt. of components per day when set to give a case depth of 0·040 in.—M. A. K.

Surface Treatment of Metals. L. G. W. Palethorpe. (*Machine Shop Mag.*, 1954, **15**, Oct., 584–592). Two methods of obtaining hard wear-resistant surfaces are described. One deals with the drip-feed gaseous cementation process, while the other describes the Cassel 'Sulfinuz' process for obtaining a sulphur-rich layer on the surface of parts.—M. A. K.

Flame-Hardening of Steels. C. Ciffo. (*Ing. Mecc.*, 1954, **3**, Sept., 25–30; Oct., 25–28). [In Italian]. After examining flame-hardening procedure and the materials suitable for this type of hardening, the author describes the equipment for (*a*) rapid flame-hardening, and (*b*) progressive flame-hardening.

Flame-Hardening. E. F. Green. (*Proc. International Acetylene Assoc.*, 1948, 1949, and 1950, 441–449). A general description is given of flame-hardening practice. Materials which can be so hardened, the mechanical and heating equipment necessary, fuels, temperatures, methods, quenching, stress relieving, and testing and inspection are among the topics discussed.—J. E. J.

Selective Hardening by Flame Heating. V. B. Bullen and D. M. Strauchen. (*Steel*, 1954, **135**, Sept. 27, 86–88). Examples are given of how precision flame hardening can give finely controlled case and core properties.—D. L. C. P.

Induction Heating Meets Basic Automation Needs. W. K. Ginman. (*Iron Age*, 1954, **174**, Oct. 21, 221–223). Illustrated examples are given of how induction heating can be successfully coupled with mechanical devices for automatic annealing, hardening, brazing, and sizing of parts.—D. L. C. P.

Modern Heat Treating: 10—Induction Heat Treating—Selectivity Teams up with Versatility. (*Steel*, 1954, **135**, Oct. 18, 92–95). The principles and practice of induction heating are briefly explained, and examples given of its use in the production line for hardening, tempering, and stress relieving. In a new process heat-treatment takes place on one spindle of an ordinary multiple spindle automatic machine.—D. L. C. P.

Variety of Induction Heating Machines Gives Precise Hardness, Greater Output. H. Chase. (*Iron Age*, 1954, **174**, Dec. 16, 115–117). Examples are given of how induction-hardening machines are used for surface-hardening parts in the production lines at the Chrysler Corp.—D. L. C. P.

Sub-Zero Heat Treatment—Problems Met and Solved. E. H. Clark. (*Australasian Eng.*, 1954, Oct. 7, 121, 123, 125, 127, 129, 131). The first part of the article describes the development of a hardening and tempering treatment for cast Meehanite components, involving salt-bath heating and quenching at 880–900° and 195–210° C. The increase in hardness of alloy steels developed by treatment at sub-zero temperatures after conventional quench hardening is next discussed. An increase in final hardness from 63 to 68 R_c is reported for small carbon–chromium steel rings when a − 80° F. treatment is given between normal quenching and tempering.—P. M. C.

Minimize Distortion with Improved Die Design. R. V. Adair. (*Iron Age*, 1954, **174**, Nov. 18, 154–155). Three examples are given of modern press quench dies, for cases where careful design was necessary to prevent distortion of the parts during quenching, and permit adequate flow of the media.—D. L. C. P.

Improved Quench Methods Developed for Austempering, Martempering. Q. D. Mehrkam. (*Iron Age*, 1954, **174**, Oct. 28, 99–102). The theory and practice of austempering and martempering are described. The significance of the isothermal transformation curve is explained. The new 'Cataract Quench' furnace is mentioned, in which unusual quenching power is obtained by a high-velocity stream of molten salt.—D. L. C. P.

How Flame and Induction Heating Work. J. Obrebski. (*Machinist*, 1952, **96**, Mar. 22, 426–429). Heat distribution in work heated by flame or induction is quite different from that produced by furnace heating. The differences are explained.—E. C. S.

Flame Hardener Treats Cams at High Speeds. W. G. Patton. (*Iron Age*, 1952, **169**, Mar. 20, 98–99). An automatic machine for flame hardening at the Buick Motor Division is described. A 3-spindle oxygen-propane machine with integral oil quench and continuous feed is employed. Three different sizes of cam can be hardened together at the rate of 550 pieces/hr.

Some Notes on the Surface Hardening of Steels and the Use of Copper Plating for Stopping-Off. G. K. Burton. (*Sheet Metal Ind.*, 1952, **29**, Apr., 367, 368, 370). The author outlines a copper-plating sequence suitable for producing a plate which will prevent subsequent surface hardening after the component has been carburized, nitrided, or cyanide hardened. These three surface-hardening processes are briefly described.

Pipe Weld Normalizing and Stress Relieving. C. A. Anderson, D. H. Corey, and H. J. Denman. (*Welding J.*, 1952, **31**, Apr., 324–329). Improvement in the application of the 60-cycle induction heating method, is described. The metallurgical effects should not be changed by the electrical circuit changes described. Design computations and some of the lessons learned in the field are included.—U. E.

Industrial Installations for Inductive Surface Hardening. K. Kegel. (*Z.V.d.I.*, 1952, **94**, Apr. 21, 331–338). Numerous installations of different design and make are described, and their applications and performances are given—J. G. W.

FORGING, STAMPING, DRAWING AND PRESSING

Kirkstall-Repco Pty. Ltd. (*Australasian Eng.*, 1954, Aug. 7, 69, 71). A brief account is given of the new Kirkstall-Repco drop-forging plant in Melbourne, which produces automobile axles, axle components, and hubs.—P. M. C.

Automatic Equipment Leads Trends in Improving Forged Products. R. G. Friedman. (*Iron Age*, 1954, **174**, Oct. 21, 231–233). Examples of modern achievements in hot and cold forging and of recent improvements in practice are given.

Cold Forming Methods Save Materials, Lower Processing Costs. K. W. Stalker. (*Iron Age*, 1954, **174**, Dec. 23, 69–70). The increased use of cold-forming under high pressure is discussed.—D. L. C. P.

On the Temperature Distribution of the Tools for Manufacturing Steel Tubes and Pipes. E. Miyoshi. (*Sumitomo Metals*, 1952, **4**, July, 353–358). [In Japanese]. The temperature distribution in the mandrel was studied through the temperature of the water running inside. The average temperature on the outer surface is 350–450° C., but it exceeds

850° C. in the thin layer near the top, and a high thermal stress acts on the inner surface.—K. E. J.

Drawing Force through Die. Circular Arc Type Die and Straight Line Type Die. H. Yamanouchi and I. Hayashi. (*Waseda Univ., Rep. Castings Res. Lab.*, 1954, (5), 50–52). [In English]. A theoretical expression is deduced for the drawing force in any die formed by revolution of a surface, and this can be reconciled with experimental values. Minimum figures occur in the drawing stresses for each type of die at certain angles, that for the circular-arc type being greater than that for the straight-line type of die.—K. E. J.

Wire Drawing Machines of Home Production. A. Krzeminski. (*Hutnik*, 1954, **21**, (11), 362–367). [In Polish]. Descriptions of wire-drawing machines produced in Poland and their general characteristics are given.—V. G.

Processing of Wire Products in Salt Bath Furnaces. L. B. Rosseau. (*Wire and Wire Prod.*, 1954, **29**, Oct., 1150–1158). Salt-bath furnace equipment and auxiliary appliances are described. Annealing costs are quoted. Maintenance and some drawbacks of salt baths are noted. Descaling and patenting of wire are reviewed.—J. G. W.

Johnson Steel and Wire Company Modernization Program. J. R. Carter. (*Wire and Wire Prod.*, 1954, **29**, Sept., 975–977, 1034). Details of a seven-point, $500,000, modernization programme of Johnson Steel and Wire Co., Worcester, Mass., are given. It includes installation of new wire-drawing machines and modernization of heat-treatment.—J. G. W.

Die Making by the Electric Discharge Machining Process. H. V. Harding. (*Wire and Wire Prod.*, 1954, **29**, Dec., 1434, 1487). The electric discharge process of machining carbides is briefly explained and its advantages in tool manufacture compared with conventional machining are listed.—J. G. W.

Continuous Wire Drawing and Packaging. W. H. Richardson. (*Wire and Wire Prod.*, 1954, **29**, Dec., 1430–1433, 1482–1486). The Payoff barrel for storing wire, developed and marketed by the Driscoll Wire Co., is described and illustrated for use in conjunction with a wire-drawing machine.—J. G. W.

Stress Distribution and Deformation Energy in the Deformation of Tube. T. Okamoto. (*Sumitomo Metals*, 1952, **4**, Oct., 411–423). [In Japanese]. A mathematical treatment, applicable to industrial tube manufacture, is given for three-dimensional plastic deformation, based on a 'deformation factor' and its mean value. Stress distribution, deformation energy, and the pressure difference between the outside and inside may be calculated.—K. E. J.

ROLLING-MILL PRACTICE

New Methods of Examining the Relative Movement of Metal in Contact with Rolls. J. Bazan. (*Hutnik*, 1954, **21**, (10), 316–320). [In Polish]. Three methods of investigating the relative movement of metal in contact with rolls are described.

The Production of Self-Hardening, Threaded High-Tensile SIGMA Steels. R. Zettwitz and M. Naumann. (*Tech. Mitt.*, 1953, (2), Dec., 76–84). The authors describe the melting and rolling of high-tensile rods of two types of steel; one used by the German State Railways for prestressed concrete sleepers and the other for bridges. (SIGMA is the trade name registered by Hüttenwerk Rheinhausen AG. for these steels).—R. A. R.

The New Plate Mill at Australian Iron and Steel Ltd. Kembla Works. (*B.H.P. Rev.*, 1954, **31**, June, 8–10). An illustrated description is given of the new plate mill installed at Port Kembla. This produces plates from $\frac{3}{16}$ to $4\frac{1}{2}$ in. thick in widths from 24 to 80 in., and in lengths up to 60 ft.—L. D. H.

Modern Steel Plant Teams Continuous Casting with Planetary Mill. E. C. Beaudet. (*Iron Age*, 1954, **174**, Nov. 4, 113–120).

One Pass Reduction on New Atlas Hot Strip Mill. (*Canad. Metals*, 1954, **17**, Dec., 22–24). A short illustrated account of a planetary hot mill capable of reducing hot slabs by 95% in one pass which is in operation at the Atlas Steel Co., Welland, Ontario. The mill is capable of handling slabs $2\frac{1}{4}$–3 in. thick up to 20 in. wide by 8–32 ft. long. The products are 0·062–0·187 in. thick strip and sheet bar up to 1 in. thick.

Mill Expansion with Few Production Tieups. (*Steel*, 1954, **135**, Nov. 15, 136–139). The schedule is given by which two new stands were added to an 86-in. hot mill at Kaiser Steel Co.'s Fontana plant, with a total of only 16 days lost production.—D. L. C. P.

Last Expansion Piece in Place. (*Steel*, 1954, **135**, Oct. 18, 100–102). New facilities provided by the $96 million rebuilding programme of the Allegheny-Ludlum Steel Corp. are described. The last of the new installations, a 4-stand tandem strip mill for coils up to 48 in. wide, has been started up. Some general features of the mill and melting shop are described.—R. A. R.

Semicontinuous Processing Improves Strip Steel Quality, Cuts Handling. J. B. Delaney. (*Iron Age*, 1954, **174**, Oct. 14, 140–141). The production line for steel strip for bandsaw blades at Jessop Steel Co., Pa., is described.—D. L. C. P.

Finish-Rolling of Cold-Rolled, Low-Carbon Steel Sheets. S. E. Friedrich. (*Bol. Assoc. Brasil Met.*, 1954, **10**, Apr., 87–96). [In Portuguese]. It is shown that shatter-cracks or Lüder's lines, which may be formed in the fabrication of cold-rolled and annealed sheet or strip, can be avoided if an efficient, light finish-rolling (about $\frac{1}{2}$–1% reduction normally) is given after annealing. The material must be fabricated reasonably quickly after this, otherwise ageing redevelops the yield point.—P. S.

Study on the Piercer Plug. T. Ikeshima and T. Morishima. (*Fuso Metals*, 1952, **4**, Jan., 252–255). [In Japanese]. For piercer plugs for the Stiefel–Mannesmann mill, cast steel containing 0·3% C, 3·0% Cr, 0·5% Ni, and < 0·6% of Si and Mn gave the best results. Optimum heat-treatment was determined, and forging was found to be effective.—K. E. J.

Automatic Control of Operations in Sheet Mills. M. Krejčík. (*Hutnické Listy*, 1954, **9**, Dec., Supplement, 39–42). [In Czech]. Equipment for the control of roll pressure and sheet thickness is discussed.—P. F.

The Use of X-Rays for the Continuous Measurement of Sheet Thickness. M. Vinopal. (*Hutnické Listy*, 1954, **9**, Dec., Supplement, 35–38). [In Czech]. Equipment of Czechoslovakian and U.S. manufacture for measuring sheet thickness is discussed.—P. F.

Mechanisation in Rolling Mills. J. Petr. (*Hutnické Listy*, 1954, **9**, Dec., Supplement, 31–35). [In Czech]. The use of servo-mechanisms for sheet-thickness control, and automatic coiler control, is discussed, and the savings which will probably result are estimated.—P. F.

Estimation of Temper-Rolling Reductions of Mild-Steel Sheet by an X-ray Diffraction Method. P. W. Wright and B. B. Hundy. (*J. Iron Steel Inst.*, 1955, **181**, Sept., 40–43). [This issue].

MACHINERY FOR IRON AND STEEL PLANT

Automatic Performance Control in Metallurgical Plants. J. Křečan. (*Hutnické Listy*, 1954, **9**, Dec., Supplement, 50–53) [In Czech]. The scope of a projected central automatic recorder of the important physical variables in production, which is also operating as quality recorder and controller, is discussed. Its installation is expected to lead to considerable economies in production.—P. F.

Automatic Control in the Metal Industry from the Point of View of Instrument Development. Pravda. (*Hutnické Listy*, 1954, **9**, Dec., Supplement, 48–50). [In Czech]. The principles and applications of instruments use pin automatic control systems, e.g. for the control of temperature, pressure, gas flow, are discussed.—P. F.

Instruments for the Automatic Control of Metallurgical Processes. V. Klásek. (*Hutnické Listy*, 1954, **9**, Dec., Supplement 14–16). [In Czech]. The types of instruments produced and projected for early production in Czechoslovakia, as well as other instruments for automatic control are discussed.

The Tasks of Automatic Control in the Metal Industry. A. Förchtgott. (*Hutnické Listy*, 1954, **9**, Dec., Supplement 3–4). [In Czech]. Tasks include primarily the further development of instruments for the automatic control of blast-furnace performance, and the production of new Czechoslovak instruments to replace those imported.—P. F.

Fundamentals of Automatisation. L. v. Hamos. (*Gjuteriet*, 1954, **44**, Dec., 205–211). [In Swedish]. The basic components of automatic control systems are described with some examples.—R. A. R.

Formula for Water. (*Steel*, 1954, **135**, Nov. 1, 94–96). The arrangements for dealing with water at the new Fairless works

of U.S. Steel Corp. are outlined. As much as 230 million gal./day are borrowed from the Delaware River, and treated for use in the iron and steelworks.—D. L. C. P.

Automation Pays Off in Steel Mill Handling System. W. Boehm. (*Iron Age*, 1954, **174**, Nov. 11, 130–132). A system of conveyors and transfer mechanisms installed for moving coils of steel wire from the reels to storage and despatch is described.

Organization for Maintenance. J. L. Gaskell. (*J. Iron Steel Inst.*, 1955, **181**, Sept., 71–83). [This issue].

WELDING AND FLAME-CUTTING

New Welding Process Cuts Costs and Welding Times. (*Welding J.*, 1954, **33**, Dec., 1187–1188); **Old Processes Refined.** C. H. Jenning and H. J. Bichsel. (*Steel*, 1954, **135**, Nov. 1, 84–85). A new consumable electrode inert-gas arc-welding process developed by Westinghouse Elec. Corp. is presented. A new grade of coated wire is used—' West-ing-arc MS–20.' Straight polarity operation is possible at a high rate and with little spatter, and the process can be used economically on mild steel.—D. L. C. P.

The Production of Welded Stainless Steel Pipe. A. Grodner. (*Welding J.*, 1954, **33**, Dec., 1171–1174). The production, welding, heat-treatment, and inspection (including radiographing) of stainless-steel piping of $\frac{1}{4}$ in. and $\frac{7}{16}$ in. thickness, and 3 in. and 14 in. dia., respectively, is described.—U. E.

Improved Rods and Techniques Overcome Crack Sensitivity in Magnet Steel Welds. J. J. Obrzut. (*Iron Age*, 1954, **174**, Oct. 28, 90–91). The technique used to weld the cast steel case of an electromagnet to the cast manganese-steel lifting face is described. Low-temperature electrodes were used to avoid damage to the insulation on the coil windings.—D. L. C. P.

Heavy Cutting in the Steel Mill. L. P. Elly. (*Proc. International Acetylene Assoc.*, 1948, 1949, and 1950, 307–315). The cutting of heavy-sectioned steel by means of the oxy-acetylene torch is discussed. The equipment required and operations involved in ingot cropping, roll line cutting, riser cutting, and reduction of scrap are described.—J. E. J.

Oxy-Acetylene Flame Shape-Cutting in Railroad Shops. F. B. Rykoskey. (*Proc. International Acetylene Assoc.*, 1948, 1949, and 1950, 298–303). Oxy-acetylene shape cutting practice in railroad shops is described, and the method is compared with forging. Methods of multiple torch cutting and stack cutting are discussed.—J. E. J.

Oxy-Acetylene Flame-Hardening in Commercial Heat-Treatment. J. T. Howat. (*Proc. International Acetylene Assoc.*, 1948, 1949, and 1950, 219–227). The operation of flame-hardening installations for commercial heat-treatment is described. The costs and controllability of the general process are discussed, and examples are given of the hardening of steel and iron components of varying size.—J. E. J.

Use of Oxy-Acetylene for Scarfing in the Steel Mill. G. Mershot. (*Proc. International Acetylene Assoc.*, 1948, 1949, and 1950, 212–216). The use of the oxy-acetylene torch for removing surface defects in steel blooms, billets, and slabs is described. An account is given of the development of starting rods to overcome initial gouging. Methods of handling the steel are discussed.—J. E. J.

Standardization of Quality and Plate Size of Shipbuilding Steel. W. Janssen. (*Stahl u. Eisen*, 1955, **75**, Jan. 13, 39–46). The author discussed the failures occurring in welded ships which led to amendments of the specifications. The specifications of British Lloyds, German Lloyds, Bureau Veritas, Norwegian Veritas, Registro Italiano Navale, and the U.S. Bureau of Shipping are discussed and compared, and suggestions are made for their standardization of these specifications. The author recommends standardizing the sizes of shipbuilding plate and stresses the advantages to be gained.

High-Strength Weldable Steel: Development of Fortiweld—1949–1953. W. E. Bardgett and L. Reeve. (*Iron Steel*, 1954, **27**, Oct., 479–485; Nov., 514–518). The authors discuss the development of the molybdenum-boron steel "Fortiweld" and its properties, including the mechanical properties as-rolled and after heat-treatment, creep, fatigue resistance, deep drawing properties, machinability, corrosion resistance, and weldability.—G. F.

Fortiweld. A New Development in Weldable High-Tensile Steel. Part II. H. F. Tremlett. (*Welding Metal Fab.*, 1955, **23**, Jan., 15–20. For abstract of Part I *see J. Iron Steel Inst.*, 1955, **179**, Feb., 201). After comparing the properties of Fortiweld and steels of the British Standard P68 type with respect to strength and weldability practical examples are given of the exceptional freedom from hard zone cracking of Fortiweld. Consideration is given to metal arc, argon arc and oxy-acetylene welding of Fortiweld sheets.—U. E.

Automatic Metal Inspection. (*Metal Ind.*, 1954, **85**, Oct., 8, 311, 312). By combining digital computers and other electronic devices with ultrasonic flaw detector techniques, Sperry Products Inc., U.S.A., have developed a precision instrument (called SIMAC, for sonic inspection measurement and control) for automatic parts inspection as production line procedure. The immersion technique (under water) is employed for the ultrasonic inspection, the results being recorded automatically in accordance with a scanning programme for each component, determined and carried out by feeding a punched controlling tape or card into the instrument.—P. M. C.

Results of Service Test Program on Transition Welds between Austenitic and Ferritic Steels at the Philip Sporn and Twin Branch Plants. G. E. Lien, F. Eberle, and R. D. Wylie. (*Trans. Amer. Soc. Mech. Eng.*, 1954, **76**, Oct., 1075–1083). The results of tests of *programme used to determine* the effect of high temperature and pressure on dissimilar-metal welds in two power stations are given. Test vessels were used in which 2·2-% Cr 1%-Mo steel and stabilized 18/10 steel were joined by stabilized 18/10 weld metal. The vessels were cycled in the range 300–1050° F. at 2000 lb./sq. in. The tests showed that surface notches had formed together with cracks below the surface in the ferritic steel adjacent to the dissimilar weld fusion interface.—D. H.

Effects of Prestressing on Fatigue Strength of Spot-Welded Stainless Steels. A Choquet, V. N. Krivobok, and G. Welter. (*Welding J.*, 1954, **33**, Oct., 509s–523s). The effects of prestressing on fatigue strength of spot-welded stainless steels was investigated. In addition to prestressing by hydrostatic means, simple compression, tension, and hand-peening methods will result in significent increases in fatigue characteristics.—U. E.

Metallurgical Aspects of Welding Precipitation-Hardening Stainless Steels. C. W. Funk, and M. J. Granger. (*Welding J.*, 1954, **33**, Oct., 496s–508s). Aircraft materials of construction are compared with respect to yield-strength/weight ratio at ambient and elevated temperatures, corrosion resistance and characteristics during fabrication. The microstructure and its effect on the mechanical properties are discussed. Porosity in welds is probably due to trapped gas.—U. E.

Chromium Recovery During Submerged Arc Welding. F. G. Harkins. (*Welding J.*, 1953, **32**, Feb., 111s–112s). The author discusses underbead weld cracking due to chromium losses in stainless steel when welded by the submerged arc welding process.—U. E.

MACHINING AND MACHINABILITY

Applications Increase As Leaded Steels Take Cut at Machining Costs. (*Steel*, 1954, **135**, Oct. 25, 159–162). The widening applications of leaded steels are described and examples given of their successful introduction. Treated stainless steel may be as easy to machine as a straight carbon grade.—D. L. C. P.

Force, Temperature Measurements, Rapid Guide to Tool Life Evaluation. E. A. Loria and D. R. Walker. (*Iron Age*, 1954, **174**, Nov. 18, 156–158). Machining tests on four grey cast irons are described, which indicate that cutting force and temperature measurements can provide an estimate of the tool life to be expected. It is concluded that under given operating conditions and with materials having similar machining properties, the method can be used instead of more lengthy wear tests.—D. L. C. P.

Four Factors Determine Selection of Leaded Steels. F. J. Robbins. (*Iron Age*, 1954, **174**, Oct. 7, 117–120). The factors determining the suitability of specific jobs for economical employment of leaded steels are described. Examples are given of how improved machinability, tool life, and part finish obtainable with lead-bearing steels may justify their extra cost.—D. L. C. P.

Band Grinding or Disc Grinding? Part 6. G. Pahlitzsch and H. Windisch. (*Metalloberfläche*, 1954, **8**, Dec., A180–A187). This final paper summarizes the results of previous articles and gives recommendations for the use of both types of grinder.—L. D. H.

CLEANING AND PICKLING

Straight Line Flow Ends Cleaning Room Bottleneck. R. H. Herrmann. (*Foundry*, 1954, **82**, Dec., 94–99, 220–222, 224). The main feature of the recently modernized cleaning room at Empire Steel Casting Inc., Reading, Pa., is a network of waist-high roller conveyors which transport the castings through the processes of gate removal, grinding, chipping, and welding.—B. C. W.

Castings Pickled in Half the Time. R. H. Herrmann. (*Foundry*, 1954, **82**, Dec., 135, 138). The equipment recently installed at the Lebanon Steel Foundry, Lebanon, Pa., for pickling and passivating stainless-steel castings, and for pickling carbon and low-alloy steel castings, is briefly described.

In-Line Pickling Setup Aids Continuous Production. P. K. Dubin and F. A. Locke. (*Iron Age*, 1954, **174**, Dec. 23, 62–64). The arrangements in a new tank pickling shop for descaling alloy and stainless-steel rod and wire are given. Modern exhaust systems and acid-resistant materials are employed.

PROTECTIVE COATINGS

External Exchangers Stem Chemical and Electrolytic Corrosion. C. Buck. (*Iron Age*, 1954, **174**, Dec. 30, 50–51). The advantages of placing the heating or cooling equipment outside the tank containing pickling, plating, or anodizing solutions are explained, and constructional materials are recommended.

Electro-deposition of Alloys. A. Whittaker. (*Machinery*, 1954, **85**, Dec. 24, 1350–1353). The author broadly discusses the scope and operation of the alloy plating processes. Types of alloys suitable for deposition, methods and principles, and the production of bearing surfaces are described.—M. A. K.

Time Studies Lead to Greater Output, Closer Control in Diversified Plating. F. B. Dugan. (*Iron Age*, 1954, **174**, Oct. 7, 122–129). The design and running of the plating shop at Westinghouse Electric Corp., Baltimore, are described. A variety of parts for cleaning, anodizing, electroplating, buffing, and laquering are handled.—D. L. C. P.

Electroless Plating Comes of Age. II. A. Brenner. (*Metal Finishing*, 1954, **52**, Dec., 61–68). Equipment used in industrial systems for chemical nickel plating and methods of control are described. A method is given for the determination of the hypophosphite content of the bath. The economics of the process are discussed.—A. D. H.

Electrolytic Nickel-Clad Plate Offers Low-Cost Corrosion Protection. S. G. Bart. (*Iron Age*, 1954, **174**, Oct. 28, 87–89). Lectro-Clad plates, made by Bart Mfg. Corp., N.J., are mild steel plates with a 0·006–0·020 in. electrodeposited nickel coating; the method of manufacture and fabrication possibilities are described.—D. L. C. P.

Production of Nickel-plated Pipes for Atomic Energy Installations. (*Machinery*, 1954, **85**, Dec. 31, 1398–1402). The production of internally nickel-plated pipes from 20 to 54 in. in dia. for handling highly corrosive and radioactive gases for the U.S. Atomic Energy Commission, and manufactured by Alco Products Division of American Locomotive Co., U.S.A., is discussed.—M. A. K.

Accurate Combustion Control Improves Galvanizing Quality and Economy. (*Indust. Heating*, 1954, **21**, Oct., 1963–1966, 2106). The burner-design of the galvanizing kettle described gives flexibility and accuracy of control.—A. D. H.

Electrolytic Deposits of Zinc. (*Met. Constr. Mecan.*, 1954, **86**, Dec., 967–969). A short account of the techniques used for the electrolytic deposition of zinc and the future prospects of this type of coating are given.—R. G. B.

Tin Mill Products. (*Amer. Iron Steel Inst. Steel Prod. Man.*, 1954, July, 5–28). After a brief sketch of the history of tin-mill production, modern methods of production in the U.S.A. are outlined. Tin-plate, short terne, plate and back plate are described.—E. C. S.

Compact Unit Plates Heavy Ductile Coatings on Steel Wire. H. Kenmore. (*Iron Age*, 1954, **174**, Nov. 11, 117–119). A process developed by the Kenmore Metals Corp., Jersey City, is described. Heavy ductile coatings of copper, nickel and other metals are electroplated to steel wire, which spirals through the plating baths.—D. L. C. P.

The Effect of Ultrasonic Waves on the Electrodeposition of Copper. W. R. Wolfe, H. Chessin, E. Yeager, and F. Hovorka. (*J. Electrochem. Soc.*, 1954, **101**, Dec., 590–596).

Dip Valves for Higher Performance. (*Steel*, 1954, **135**, Oct. 11, 114–115). The 'Aldip' process, and its application to coating car-engine valve-seat faces are described. The parts are dipped through a molten fluxing salt into molten aluminium. An alloy shell 0·001–0·0015 in. deep is formed which is ideal for the conditions encountered.—D. L. C. P.

Formation of "Tears" on Galvanized Sheets. H. J. Wiester and D. Horstmann. (*Stahl u. Eisen*, 1953, **73**, July 2, 906–908). Metallographic examination has shown that retraction or de-wetting after hot galvanizing is due to oxide residues on the surface of steel sheets.—J. P.

POWDER METALLURGY

Properties of Metallic Phases as a Function of Number and Kind of Bonding Electrons. N. Engel. (*Powder Met. Bull.*, 1954, **7**, Dec., 8–18). In a new theory of bonding, atomic quantum states are assumed to be essentially invariable, but electrons may change quantum states. Bonding is due to cancellation of electronic fields, and metallic properties result from vacancies in the bonding shell. The theory accounts for the formation of metallic lattices and the intermediate phases in the binary systems of transition metals and small atoms.—K. E. J.

The Friability Test as a Method of Evaluating Sinter Cake. I. Sheinhartz and H. M. McCullough. (*Powder Met. Bull.*, 1954, **7**, Dec., 22–24). The possibility of adapting the A.S.T.M. friability test (developed for coal) for sinter cake was explored. The test enables chemical impurities and other inclusions to be detected, thus making it possible to rework or scrap the material before expensive processing operations are performed.—K. E. J.

Metal Powders and Powder Metallurgy—Recent Advances. H. W. Greenwood. (*Machinery Lloyd, European Ed.*, 1954, **26**, Nov. 13, 65–67). A short review of recent advances on powder metallurgy is given. Important advances mentioned are direct rolling of copper powder to sheet prior to sintering, alloying by interfusion of metals in powder form, exothermic metal mixtures, the use of iron powder in powder-washing of castings, the use of Al–Fe powder in scrap cutting, the use of infiltration for improving the density, hardness, and strength of sintered products, impregnation to improve surface conditions and machinability, and, in the case of tungsten, impregnation with non-alloying copper which is evaporated out after machining.—J. E. J.

A Combined Dilatometer and Electrical Resistivity Apparatus for Studies in Powder Metallurgy. N. A. McKinnon. (*J. Sci. Instruments*, 1954, **31**, Oct., 383–385). An apparatus is described for the measurement of the expansion and contraction of pressed metal-powder compacts by means of a dial gauge, and of its electrical resistance by measurement of drop in potential when a known current is flowing.—L. D. H.

Production of Iron Powder by Reduction. M. Guédras. (*Mét. Constr. Mécan.*, 1954, **86**, Dec., 913–914). A brief account of the production of fine iron powder of high purity (99·84% Fe) by reducing iron with hydrogen is described.

PROPERTIES AND TESTS

Ductility Transition and Cold Brittleness. T. Yokobori. (*J. Phys. Soc. Japan*, 1953, **8**, Jan.-Feb., 107–109). Ductility transition and cold brittleness were studied from the standpoint of stochastic theory, with failure and fracture treated as reaction rate processes. The relation between deformation velocity V_B and the absolute temperature for brittle fracture T was determined, and the effect of notch radius on transition, the size effect, and scatter of brittle strength were satisfactorily interpreted.—J. G. W.

Failure and Fracture from Standpoint of Stochastic Theory. T. Yokobori. (*J. Phys. Soc. Japan*, 1953, **8**, Jan.-Feb., 104–106). Treating failure and fracture of metals as a mark-off chain the physical meanings of transition probabilities were interpreted as corresponding to nucleation rates. Other mechanical phenomena of the metallic state were also all satisfactorily interpreted.—J. G. W.

The Size Effect in Fatigue of Notched Steel Specimens Loaded under Reversed Direct Stress. A. Hikata. (*Government Mech. Lab. Bull.*, 1954, (2)). Direct-stress fatigue tests were carried out on mild-steel specimens of 53 kg./sq. mm. U.T.S.

The notch in each section was a hyperbolic groove, and the notched sections for all the specimens were geometrically similar. Results confirm that the size effect in fatigue is mainly due to the stress gradient in the specimen. The distance of the critical-stress point from the tip of the notch is shown to be independent of the size of the specimen.—E. A. C.

The Small Constant Paramagnetic Properties of Certain Cobalt and Iron Compounds. A. Serres. (*J. Phys. Radium*, 1953, **14**, Dec., 689–690). The coefficients of magnetization of certain compounds of cobalt and iron have been measured; a small constant value ($\chi_A \leqslant 80 \times 10^{-6}$) is obtained at saturation.—J. O. L.

Oxidic Permanent Magnets from Barium Oxide and Ferric Iron Oxide. H. Fahlenbrach and W. Heister. (*Techn. Mitt. Krupp*, 1954, **12**, Jan., 47–51). The development and magnetic properties of permanent magnets having the composition $BaO.6Fe_2O_3$ are described, and the lines of their further development indicated.—L. D. H.

The Torductor and the Pressductor, Two Magnetic Stress Gauges of New Type. O. Dahle. (*I.V.A.*, 1954, **25**, (**5**), 221–238). [In English]. Details are given of the design and use of two new stress gauges which make use of magnetic isotropy in magnetic materials under mechanical stress. These are the torsion inductor—a torque meter for rotating shafts which works without slip rings or other attachments—and the press inductor which is a pressure meter for high compressive forces giving an exceptionally high output power.—G. G. K.

Heat Treatment of Dispersed System Magnet Steel (II). M. Chubachi. (*Fuso Metals*, 1951, **3**, Jan., 14–19). [In Japanese]. The magnetic properties of the alloy are greatly affected by the cooling conditions in the mould. With green sand moulds, the casting surface is initially supercooled, and the mould surface sinters; heat propagation is disturbed and slow cooling ensues. Heat propagation is more rapid in oil sand moulds, whose cooling ability is superior even at 1300° C.—K. E. J.

What We Need to Know about Creep. J. E. Dorn and L. A. Shepard. (Symposium on Effect of Cyclic Heating and Stressing on Metals at Elevated Temperatures: *Amer. Soc. Test. Mat. Spec. Tech. Pub.* 165, 1954, 3–30). A method of approach to the study of high temperature creep is presented in which the effects of the individual variables of temperature, stress, and metal structure as affected by creep can be isolated and separately tested. Testing methods, results and correlations for pure metals and dilute alloys are outlined, and problems requiring further clarification are discussed.—B. G. B.

The Problem of Thermal Stress Fatigue in Austenitic Steels at Elevated Temperatures. L. F. Coffin, jun. (Symposium on the Effect of Cyclic Heating and Stressing on Metals at Elevated Temperatures: *Amer. Soc. Test. Mat. Spec. Tech. Pub.* 165, 1954, 31–52). Mechanisms for strain localization are discussed and experiments are reported for specimens designed to exhibit such localizations. Relationships between plastic strain change and cycles to failure are developed from tests performed on uniform specimens subjected to both cyclic strain at constant temperature and constrained cyclic thermal strain. These relationships are used to predict failure for the localized strain experiments.—B. G. B.

Effect of Temperature Cycling on the Rupture Strength of Some High-Temperature Alloys. J. Miller. (Symposium on the Effect of Cyclic Heating and Stressing on Metals at Elevated Temperatures: *Amer. Soc. Test. Mat. Spec. Tech. Pub.* 165, 1954, 53–66). Cyclic temperature rupture tests have been conducted on four different high temperature alloys. The results of the tests are compared with calculated rupture lives made using constant-temperature rupture data and integrating the life expenditure over a complete temperature cycle. The calculated and observed values correlate very well although, in general, the actual values are somewhat lower than those calculated.—B. G. B.

Experiments on the Effects of Temperature and Load Changes on Creep Rupture of Steels. G. V. Smith and E. G. Houston. (Symposium on the Effect of Cyclic Heating and Stressing on Metals at Elevated Temperatures: *Amer. Soc. Test. Mat. Spec. Tech. Pub.* 165, 1954, 67–78). Variation in stress or temperature during creep-to-rupture tests may result in an alteration in the rate of creep or time to rupture. The authors do not consider it possible to generalize on these changes on the basis of the relatively few results now available.

The Effects of Defects in a Metal on Its Electrical Properties. M.-J. Druyvesteyn. (*Revue Générale des Sciences Appliquées*, 1954, **2**, (1), Reprint). Work on the influence of plastic deformation on electrical resistivity is briefly described. The various types of imperfections are discussed.—T. E. D.

Ultrasonics for the Metalworker. T. A. Dickinson. (*Sheet Metal Ind.*, 1954, **31**, Dec., 1028–1032, 1038). Methods which have been used commercially to produce ultrasonic energy, such as whistles, sirens, and magnetostrictive, crystal, electrostrictive and mechanical transducers, are very briefly described. A general review is then given of such industrial applications as the soldering of aluminium, flaw detection, cleaning and degreasing, the machining of brittle materials, and precipitation of industrial smoke. (30 references).—P. M. C.

Some Factors of Importance in Ultrasonic Testing. J. B. Morgan. (*Non Destructive Test.*, 1954, **12**, May-June, 13–18). The author describes the results of an investigation to determine the effects of several factors in ultrasonic testing which influence the amplitude or height of the indication from a flaw, as displayed on the cathode-ray tube screen. These factors include the distance of the flaw below the surface, the geometry of the article, the frequency, size and sensitivity of the transducer, and the performance of the ultrasonic equipment. An amplitude-distance curve, placed over the cathode-ray tube screen, is proposed after standardization of the searching units and instrument.—P. M. C.

Inspection of Metals with Ultrasonic Surface Waves. W. C. Minton. (*Non-Destructive Test.*, 1954, **12**, July-Aug., 13–16). The depth of penetration of surface waves at different test frequencies is discussed and sensitivity to small flaws and to interference from rough surfaces is described. The efficiency and practicability of several methods of producing surface waves (using X and Y-cut quartz crystals and plastic wedges) are compared. Propagation of these waves around contours in the pieces under test is shown, and a number of successful applications to actual testing problems are discussed and illustrated.—P. M. C.

Magna Scanning. A. N. Haig. (*Non Destructive Test.*, 1954, **12**, May-June, 27–28). Brief details are given of a novel radiographic technique for the examination of long objects, e.g. Winchester rifles. Direct geometrical enlargement and scanning are combined to produce a radiograph with a 20 MeV. Betatron on a film 40 in. wide and 120 in. long.—P. M. C.

Detection of Defects by Means of Probes Giving Transverse Ultrasonic Waves. F. Ramirez Gomez. (*Inst. Hierro Acero.*, 1954, **7**, Oct.-Dec., 436–450). [In Spanish]. Illustrations are given to show the advantages of using only transverse ultrasonic waves for the detection of defects in thin, irregularly-shaped, or non-planar objects. The principles for the design of probes, of constant angle of incidence, for plane and curved surfaces are discussed at length; variable angle probes are also described. Apparatus, probes, and industrial applications of these methods are illustrated.—P. S.

Immersed Ultrasonic Inspection with Automatic Scanning and Recording or Warning Signal. J. C. Smack. (*Non Destructive Test.*, 1954, **12**, May-June, 29–33). Repetitive ultrasonic inspection of a large number of the same part can now be done, and the results recorded, by automatic programming. Stepped sequence and punched tape systems are used to set up a complete coverage of the inspected parts. The complete assembly of tank scanner and electronic equipment is designated "SIMAC" (Sonic Inspection Measurement and Control).—P.M.C.

Non-Destructive Testing of Metals by Means of a Magneto-Inductive Coil Probe. H. Breitfeld. (*Metall*, 1955, **9**, Jan., 14–22). Details of the performance of the Sigmatest inductive coil instrument are reported, as applied to non-ferromagnetic materials.—J. G. W.

A High-Temperature X-Ray Camera. J. R. Johnson. (*J. Amer. Ceram. Soc.*, 1954, **37**, Aug., 360–362). An X-ray camera capable of operating with samples at up to 2200° C. is described. The specimen is heated by a simple tantalum resistance heater. Temperature control is maintained by a constant power input. A sliding film holder permits a number of successive pictures to be taken without disturbing the specimen or apparatus.—D. L. C. P.

Effects of Cyclic Overloads on the Creep Ratio and Rupture Life of Iconel at 1700 and 1800° F. R. H. Caughey and W. B. Hoyt. (Symposium on the Effect of Cyclic Heating and Stressing on Metals at Elevated Temperatures: *Amer. Soc. Test. Mat. Spec. Tech. Pub.* 165, 1954, 79–104).

The Creep-Rupture Properties of Aircraft Sheet Alloys Subjected to Intermittent Load and Temperature. G. J

Guarnieri. (Symposium on Effect of Cyclic Heating and Stressing on Metals at Elevated Temperatures: *Amer. Soc. Test. Mat. Spec. Tech. Pub.* 165, 1954, 105–148).

Constant and Cyclic-Load Creep Tests of Several Materials. W. F. Simmons and H. C. Cross. (Symposium on Cyclic Heating and Stressing on Metals at Elevated Temperatures: *Amer. Soc. Test. Mat. Spec. Tech. Pub.* 165, 1954, 149–161). Constant load and cyclic load creep tests were made on sheet specimens of a low alloy and a stainless steel and aluminium alloy. Under the conditions of the tests cycling the load did not increase the rate of creep and no evidence of recovery during the low-load part of the cycle was found.—B. G. B.

The Effect of Composition on the Scaling of Fe–Cr–Ni Alloys Subjected to Cyclic Temperature Conditions. H. L. Eiselstein and E. N. Skinner. (Symposium on Cyclic Heating and Stressing on Metals at Elevated Temperatures: *Amer. Soc. Test. Mat. Spec. Tech. Pub.* 165, 1954, 162–172). The scaling behaviour of a number of Fe–Cr–Ni alloys in air involving a cycle of 15 min. heating followed by 5 min. air cooling has been studied. Nearly all alloy compositions were satisfactory at 1400° and 1600° F. Scaling at 1800° F. is pronounced for alloys containing $< 35\%$ Ni and $< 20\%$ Cr at the low end of the nickel range and $< 15\%$ chromium at the high end.

Contribution to the Study of Secondary Hardening of Low-Alloy Ferritic Steels and its Applications to Creep. A. Portevin, A. Constant, and G. Delbart. (*Compt. Rend.*, 1954, **239**, July **12**, 138–141). A ferritic steel was heat-treated in such a way that there was precipitation of fine carbides of vanadium in the course of heating under tension, resulting in reduction of creep. The steel studied contained 0·15% C, 1·05% Cr, 1·05% Mo, and 0·25% V. If the steel was slowly cooled at 60° C./hr. or 300° C./hr. after heating at 950° or 1050° C., and then submitted to creep tests at 550° C., enormous resistance to creep was found compared with those samples treated according to classical methods. There was no increase in brittleness.—T. E. D.

Effect of Certain Elements on the Graphitization of Steel. R. J. Fiorentino, A. M. Hall, and J. H. Jackson. (*Trans. Amer. Soc. Mech. Eng.*, 1954, **76**, Oct., 1123–1130). The effects of Al, N, Cr, Mn, Si, S, and P on graphitization of steel are given. Experimental steels were heat-treated by normalizing at 1700° F. or water-quenching from 1360° F., bead welded and tested for graphitization at 1025° F. for periods of up to 8000 hr. The number of graphite nodules per unit area, the average nodule diameter and the percentage conversion of carbide to graphite were measured as functions of time. It was found that the graphitization process, whether occurring in the heat-affected zone or in the parent metal, took place by a nucleation and growth mechanism, this envisages a time rate of nucleation.—D. H.

Stress-Rupture Properties of Some Chromium–Nickel Stainless-Steel Weld Deposits. R. D. Wylie, C. L. Corey, and W. E. Leyda. (*Trans. Amer. Soc. Mech. Eng.*, 1954, **76**, Oct., 1093–1106). The stress rupture properties of eleven commerical weld deposits of the austenitic Fe–Ni–Cr types with or without varying additions of molybdenum or niobium are given. Tests were carried out on the as-deposited undiluted weld deposits at temperatures of 1050–1500° F. for times up to 100,000 hr. The weld deposits exhibited lower rupture strengths and lower rupture ductility at elevated temperatures than wrought material of similar composition. Deposits which were stabilized with niobium showed better stress-rupture properties than those without.—D. H.

Corrigendum

The first abstract in the "Properties and Tests" section in the August, 1955, issue (page 391) should have read:

Yield Behaviour of Metals at Low Temperatures with Particular Reference to Some Carbon and Low-Alloy Steels. H. F. Hall and R. W. Nichols. (*J. Iron Steel Inst.*, 1955, **180**, Aug., 329–336). [This issue].

C. E. Stromeyer's Formula for Distinguishing Between Brittle and Ductile Steels. H. Schmitz. (*Stahl u. Eisen*, 1954, **74**, Dec. 16, 1741–1742). The author reviews critically the work of Stromeyer on the brittleness of steels (reported mainly in J. Iron Steel Inst. 1907 to 1910). Stromeyer's formula ($\%P + 5 \times \%N_2 \leq 0{\cdot}080$) does not, however, define the limit between brittleness and ductility, between weldable and unweldable steels, and between ordinary basic-Bessemer steel and high-quality converter steels.—T. G.

The Damping of Strained Very Low Carbon Steel. W. Köster, L. Bangert, and R. Hahn. (*Arch. Eisenhüttenwesen*, 1954, **25**, Nov.-Dec., 569–578). The damping of plastically deformed very low carbon steel shows two maxima in the 20–400° C. range. The first maximum was at about 40° C. and the second above 200° C. for a frequency of 1 c/s. The first is caused by stress relaxation owing to the exchange between the carbon and nitrogen atoms dissolved in α-iron. The second maximum at about 200° C. is caused by an interaction of dislocations and foreign atoms, and the relaxation is effected by the diffusion of the foreign atoms with an activation energy of about 36,000 cal./mole. The phenomena are discussed in the light of the dislocation theory and it is suggested that there may be a relation between the shape of damping curve and the ageing tendency of steel.—T. G.

A Simple Nomogram for the Ratios of Octahedral to Maximum Shearing Stresses and Its Physical Interpretation. G. A. Zizicas. (*J. Appl. Mech.*, 1954, **21**, Sept., 291–295). A nomogram constructed exclusively with straight lines is presented giving the ratio of the octahedral to the maximum shearing stresses for all possible stress distributions in terms of the non-dimensional ratios of the two principal stresses to the one of maximum absolute value. The physical interpretation of the nomogram is discussed.—D. H.

Explosion of a Vertical Steam Boiler. (*Brit. Engine Boiler & Elec. Insurance Co. Ltd., Technical Report*, 1955, **2**, 65–75). In this case the explosion was due to the inferior quality wrought iron plate bursting when the boiler pressure was above normal.—R. A. R.

Cracking of a Corrugated Furnace Ring. (*Brit. Engine Boiler & Elec. Insurance Co. Ltd., Technical Report*, 1955, **2**, 85–91). The cracks in this furnace ring were caused by a lamination in the plate originating from a rolled out defect in the middle of the ingot.—R. A. R.

Brittle Fracture of Some Swing Bolts. (*Brit. Engine Boiler & Elec. Insurance Co. Ltd., Technical Report*, 1955, **2**, 115–118).

Fatigue Cracking of Two Crankshafts Due to Welding. (*Brit. Engine Boiler & Elec. Insurance Co. Ltd., Technical Report*, 1955, **2**, 138–143).

Undesirable Features in Big-End Bolts Resulting from Machining. (*Brit. Engine Boiler & Elec. Insurance Co. Ltd., Technical Report*, 1955, **2**, 144–149).

Structural Changes in a Crankshaft Overheated in Service. (*Brit. Engine Boiler & Elec. Insurance Co. Ltd., Technical Report*, 1955, **2**, 152–155).

Fatigue Cracks in Some Valve Plates. (*Brit. Engine Boiler & Elec. Insurance Co. Ltd., Technical Report*, 1955, **2**, 162–164).

Fatigue Cracking of Two Chromium-Plated Crankshafts. (*Brit. Engine Boiler & Elec. Insurance Co. Ltd., Technical Report*, 1955, **2**, 165–177).

Fatigue Cracking of Welded Structures under Dynamic Loading. (*Brit. Engine Boiler & Elec. Insurance Co. Ltd., Technical Report*, 1955, **2**, 190–195).

Fracture of a Mild Steel Crane Hook. (*Brit. Engine Boiler & Elec. Insurance Co. Ltd., Technical Report*, 1955, **2**, 200–206).

Fatigue Cracking of an Excavator Shackle. (*Brit. Engine Boiler & Elec. Insurance Co. Ltd., Technical Report*, 1955, **2**, 207–212).

Brittle Rupture of a Chain Sling. (*Brit. Engine Boiler & Elec. Insurance Co. Ltd., Technical Report*, 1955, **2**, 213–214).

A Note on the Use of Chain Slings. (*Brit. Engine Boiler & Elec. Insurance Co. Ltd., Technical Report*, 1955, **2**, 215–216).

Fatigue Failures with Special Reference to Fracture Characteristics. G. A. Cottell. (*Brit. Engine Boiler & Elec. Insurance Co. Ltd., Technical Report*, 1955, **2**, 221–256).

On the Rate of Growth of Fatigue Cracks. F. A. McClintock and F. J. Ryan. (*J. Appl. Mech.*, 1954, **21**, Sept., 296–297). The note reports fatigue tests on mild steel specimens at various stress levels. These tests were carried out to determine whether the relationship between crack length and number of cycles reported by A. K. Head was valid for varying levels of stress.—D. H.

Viscous-Elastic Deformation and Fatigue Phenomena in Solids. H. Le Boiteux. (*Indust. Nat.*, 1954, (3), 47–52). Theoretical aspects of elastic and viscous behaviour of materials are considered, and the error in considering a combination of

these to be "plastic" behaviour is mentioned. Fatigue phenomena under non-alternating periodic stresses are examined.—T. E. D.

Fatigue Strength and Impact Tensile Tests with Round Open-Link Chains. K. Wellinger and A. Stunger. (*Glückauf*, 1954, **90**, Dec. 18, 1670–1672). Parallel tests of the fatigue strength of hardened and tempered and annealed round-section open-link chains showed that the strength of low and intermediate stresses was not affected by the condition of the material. The higher yield point of the hardened chain is an advantage in that higher loads can be applied. The impact tensile test, under the experimental conditions, gave a greater number of blows before fracture in the case of the hardened and tempered chains.—L. D. H.

Contribution of Crystal Structure to the Hardness of Metals. W. Chubb. (*Trans. Amer. Inst. Min. Met. Eng.*, 1955, **203**: *J. Met.*, 1955, **7**, Jan., Section 2, 189–192). The author has measured the hardness of cobalt, iron, titanium, uranium, and zirconium at temperatures up to 1000° C., and finds that the body-centred cubic structure is always the softer structure when involved in an allotropic transformation. More complex structures are inherently harder and are thus better base materials for high-strength alloys.—G. F.

The Influence of Alloying Additions on the Temperature Dependence of the Shear Modulus of Iron. N. S. Rysina and B. N. Finkel'shtein. (*Doklady Akademii Nauk S.S.S.R.*, 1954, **98**, (2), 215–217). [In Russian]. The influence of vanadium (2%), molybdenum (2%), cobalt (2%) and manganese (1·5%) additions to iron containing 0·03% of carbon on its shear modulus was investigated in the range 20° to 800° C. It was found that at room temperature, the maximum increase in the shear modulus is caused by cobalt and the maximum decrease, by vanadium. At temperatures above 500° C, the shear modulus of alloys with molybdenum, manganese, and cobalt decreases faster than that of iron–vanadium alloys.—V. G.

The Improvement of the Behaviour of Materials in the Mineral Industry by Using Alloy Steels and Special Cast Iron, and Particularly Some Nickel Alloys. B. de Borde. (*S.I.M., Documentation Métallurgique*, 1952, Apr.–May–June, 49–78). A comprehensive and well-illustrated survey is made of numerous uses of special materials when exceptionally heavy service is required. Characteristic properties of several alloy steels containing manganese, silicon, chromium-molybdenum, nickel, and nickel-chromium, as well as 'Ni-Hard', white cast iron and other types of cast iron are given. The choice of suitable materials for pneumatic drill components, compressors, wagons and railway wheels is given.—T. E. D.

METALLOGRAPHY

Polarized Light in Metallography. Its Application in the Determination of Austenite Grain Sizes. F. Muñoz del Corral. (*Inst. Hierro Acero*, 1954, **7**, Oct.-Dec., 464–467). [In Spanish]. A brief explanation of polarized light and its application to metallography is given. The determination of austenite grain sizes in quenched steels is discussed and a satisfactory method is shown to result from the examination of specimens, lightly etched in Vilella's reagent, placed between crossed nicols, and illuminated with polarized light.—P. S.

Sigma-Phase Formation in a Steel Containing 18% Chromium, 2% Molybdenum and 10% Nickel. F. Braumann and H. Krächter. (*Arch. Eisenhüttenwesen*, 1954, **25**, Sept.-Oct., 479–488). Steel with 18% Cr, 2% Mo, and 10% Ni contains ferrite after quenching from 1000° C. or above. The amount of ferrite increases with increasing quenching temperature. The ferrite is not stable below 800° C. and decomposes by a eutectoid reaction into sigma and austenite on prolonged heating. The higher the quenching temperature, i.e. the less chromium in the ferrite, the more pre-eutectoid austenite is precipitated. The amount of sigma precipitated from the supersaturated solution in the austenitic matrix is inversely proportional to the amount of pre-eutectoid austenite. A diagram of the isothermal ferrite transformation is presented.

Sigma Phase in Stainless Steel Weld Metals. L. K. Poole. (South African. Inst. Welding: *Engineer Foundryman*, 1954, **19**, Oct., 64–67). The author reviews factors controlling the formation of the sigma phase in binary and ternary alloys of iron. Methods of preventing its deleterious effect on mechanical properties are given.—A. D. H.

The Pearlite in a Chromium Steel Containing 0·4% Carbon and 3·5% Chromium. A. Schrader. (*Arch. Eisenhüttenwesen*, 1954, **25**, Sept.-Oct., 465–474). Remarkable differences in the pearlite structure between the lower and the upper part of the pearlite range are observed in a 3·5%-Cr steel with 0·4% C. In the upper part the pearlite grows in a continuous front, and, after completion of the transformation, there is no relation with the orientation of the austenite. In the lower part of the pearlite range the pearlite shows directional growth and both the carbides and the ferrite are orientated to the austenite. The directional pearlite formation is promoted by decreasing transformation temperature.—T. G.

Isothermal Austenite Grain Growth. H. B. Probst and M. J. Sinnott. (*Trans. Amer. Inst. Min. Met. Eng.*, 1955, **203**: *J. Met.*, 1955, **7**, Jan., Section 2, 215–216). The authors quote the results of an investigation of the effects of temperature, time at temperature, and previous ferrite grain size on isothermal austenite grain growth in vacuum-melted electrolytic iron. They show that changes occurring during the α–γ transformation period have a pronounced effect on subsequent austenite grain growth, and merit further investigation.—G. F.

Conditions for the Appearance of the Widmanstätten Structure in the Special Case of a Hypoeutectoid Steel. A. Portevin, A. Constant, and G. Delbart. (*Compt. Rend.*, 1954, **239**, July 19, 209–212). Isothermal transformation curves, which show, as a function of temperature and time, the constituents (pearlite, bainite, martensite) resulting from the tempering of austenite, also show the areas of formation of the Widmanstätten structure. This structure results from the separation or intergranular segregation of the ferritic pro-eutectoid in the austenite of hypo-eutectoid steels and gives rise to an acicular structure. Curves and photomicrographs are given for a hypo-eutectoid steel containing 0·36% C, 0·66% Mn and 0·22% Cr.—T. E. D.

Determination of Ferrite in Type 347 Stainless Steel Weld Deposits. W. L. Fleischmann. (*Welding J.*, 1954, **33**, Sept., 459s–468s). The ferrite content of four type 347 stainless steel weld deposits was determined by magnetic measurements using permeameter, "Magne Gage," and metallographic examination. A plot of percentage of ferrite *v.* intrinisic induction at saturation results in a fairly straight line relationship for the four weld deposits.—U. E.

The Elasticity of an Isotropic Aggregate of Anisotropic Cubic Crystals. A. V. Hershey. (*J. Appl. Mech.*, 1954, **21**, Sept., 236–240). The elasticity of a polycrystalline aggregate is expressed in terms of the elasticity of the individual grains. The stress within each grain is estimated with the aid of an analysis of the stress distribution around a spherical cavity in an isotropic medium. The strain within each grain is expressed in terms of the average stress in the polycrystal as a whole by pseudo-elastic constants which are related to the actual elastic constants. The calculated elasticities for physical tests and for X-ray diffraction measurements in polycrystals are given for a few cubic metals.—D. H.

On the Possible Development of the Theory of Dislocations. V. I. Arkharov, G. N. Kolesnikov, and A. N. Orlov. (*Doklady Akademii Nauk S.S.S.R.*, 1953, **92**, 751–754: *Nat. Sci. Foundation Translation No.* 212, Feb., 1954). The mechanism of plastic deformation presented incorporates the generation of a dislocation in the continuously regular interior regions of a lattice, its displacement over a certain range, and then the termination of this motion as a consequence of the disappearance of the dislocation by degeneration.—R. A. R.

Experimental Confirmation of the Role of Dislocations in the Growth of Crystals. A. R. Weill. (*Mem. Artillerie Fran.*, 1953, **27**, (104), 473–509). After a discussion of the theories on the growth of perfect and imperfect crystals, observations on the growth of crystals of silicon carbide, quartz, and aluminium are described. Many photomicrographs showing spiral growth are given. (37 references).—T. E. D.

Influence of Impurities on the Secondary Recrystallization of Soft Iron. R. Guihaumé. (*Compt. Rend.*, 1954, **238**, May 24, 2085–2086). Crystals of pure iron can be obtained by hot rolling followed by reheating in dry hydrogen below 910° C. Armco iron (0·035% C, $\leqslant$ 0·010% P, 0·025% S, 0·035% Mn, 0·09% Cu, 0·06% Ni) gives rise to very large crystals, but Ugiperval iron (0·04% C, 0·015% P, 0·015% S, 0·100% Mn, 0·02% Cu) does not. Experiments show that the presence of the impurity Cu_2S–FeS initiates the recrystallization, but that FeS–MnS inhibits it.—T. E. D.

On the Polygonization of Pure Iron. J. Talbot, C. De Beaulieu, and G. Chaudron. (*Compt. Rend.*, 1954, **238**, May 31, 2162–2165). The author studied the conditions under which polygonization of iron occurred, by preparing a single crystal of pure iron and subjecting it to successive annealing treatments. The treated crystal was examined by metallographic and X-ray techniques, and it is concluded that polygonization is not an intermediate stage between the cold-drawn and the recrystallized states, but, on the contrary, it is more stable than the preceding states.—G. E. D.

CORROSION

The Use of Plastics for the Construction of Pipelines and of Self-Adhesive Plastic Wrappers for Surface- and Corrosion-Protection. R. Röhm. (*Werkstoffe Korrosion*, 1954, **5**, Dec., 497–500). The author describes the growing use of plastic tubes and of adhesive plastic tapes for the protection of metal pipes exposed to corrosion by soil and other media.—J. C. H.

Rust Protection with Leaded Zinc Oxides. A. Foulon. (*Werkstoffe Korrosion*, 1954, **5**, Dec., 481–482).

Residual Currents and Corrosion. H. Grubitsch. (*Werkstoffe Korrosion*, 1954, **5**, Dec., 500–508). Extensive measurements are reported of the variation with time of the current generated by cells of the Pt/O_2 (air-saturated electrolyte) non-polarizable anode (Zn, Cd, Bi, Cu) type, both in continuously closed circuit and on reclosing the circuit after opening it for different periods. The results obtained are discussed theoretically.

Stress-Corrosion Cracking of Boiler Tubes. (*Brit. Engine Boiler & Elec. Insurance Co Ld. Technical Report*, 1955, **2**, 56–64).

Cracking of a Steam Pipe Flange. (*Brit. Engine Boiler & Elec. Insurance Co. Ld. Technical Report*, 1955, **2**, 76–79).

External Corrosion of Boiler Water-Wall Tubes. (*Brit. Engine Boiler & Elec. Insurance Co. Ld. Technical Report*, 1955, **2**, 80–84).

Corrosion of Intermittently Wetted Tubes in Boilers. (*Brit. Engine Boiler & Elec. Insurance Co. Ld., Technical Report*, 1955, **2**, 93–98).

Differential Aeration Corrosion. (*Brit. Engine Boiler & Elec. Insurance Co. Ld., Technical Report*, 1955, **2**, 99–106).

Structural Changes in the Material of a Severely Overheated Boiler Tube. (*Brit. Engine Boiler & Elec. Insurance Co. Ld., Technical Report*, 1955, **2**, 112–114). The intergranular oxidation which occurred is examined.—R. A. R.

Caustic Cracking in Steam Boilers. (*Brit. Engine Boiler & Elec. Insurance Co. Ld., Technical Report*, 1955, **2**, 119–123).

Burning of Chlorine Compressor Piston Rods. (*Brit. Engine Boiler & Elec. Insurance Co. Ld., Technical Report*, 1955, **2**, 158–161).

Testing Rust-Resisting Steels for Liability to Intercrystalline Corrosion by Electrolytic Etching in Oxalic Acid. M. A. Streicher. (*Werkstoffe u. Korrosion*, 1954, **5**, Oct., 363–368). The tendency for certain rust-resisting steels to suffer intercrystalline corrosion can be predicted by an electrolytic etching test in a 10% oxalic acid solution. The test, which is described in detail, takes about 15 min. whereas the immersion test in boiling 65% nitric acid takes 15 days.—J. C. H.

The Mechanism of the Oxidation of Iron and Alloy Steels at Elevated Temperatures. K. Hauffe. (*Metalloberfläche*, 1954, **8**, July, A97–A103). The mechanism of the oxidation of iron and alloy steels at high temperatures is discussed critically in the light of present knowledge. Proposals to increase the resistance to scaling in ferritic and austenitic steels at elevated temperatures by a suitable choice of alloying constituents are made. (27 references).—L. D. H.

The Destruction of the Passive State of Stainless Steels in Strongly Oxidizing Solutions. N. D. Tomashov and G. P. Chernova. (*Doklady Akademii Nauk S.S.S.R.*, 1954, **98**, (3), 435–438). [In Russian]. Over-passivation of stainless steels in strongly oxidizing solutions was investigated. On the bases of experiments and literature data, it is concluded that over-passivation of metals can be explained by the formation of soluble oxides of a higher valency. Thus, any shift of the potential of a metal towards positive values (by a temperature increase of the solution, or an addition of an oxidizing agent, or by anodic polarization) sufficient to bring it to the potential of the formation of a soluble oxide can cause the over-passivation.—V. G.

Geological Cells. Their Role in Certain Corrosion Phenomena. M. D. Petrocokino. (*Corrosion et Anti-Corrosion*, 1954, **2**, Mar.-Apr., 69–75; May-June, 99–105). After discussing several geophysical principles involved, and the general properties of "geological cells," the exact nature of the cells is examined and the theory considered. The danger such cells present, their mode of action, and the electric currents that might be encountered with an underground pipe are discussed. After an example of the calculation of total resistance of a circuit and loss of metal to be expected, an actual case is described.

Stress-Corrosion Cracking of Mild and Low-Alloy Steels. E. Herzog. (*Corrosion et Anti-Corrosion*, 1954, **2**, Jan.-Feb., 3–13; Mar.-Apr., 57–68; May-June, 91–97). Corrosion cracking is discussed, and research methods used to study it are described for mild and low-alloy steels. Stress measurements and rupture tests in corrosive media are described, and results and microphotographs are given and discussed. The corrosive media studied are caustic soda, nitrates, and hydrogen sulphide. Stress corrosion is influenced by the nature of the corrosive environment, internal stresses, chemical composition of the steel, and its previous thermal treatment. The electrochemical interpretation of stress-corrosion cracking is briefly discussed.

The Influence of the Crystalline Orientation of Iron on the Growth of Oxide at Its Surface at Low Oxygen Pressures and High Temperatures. J. Bardolle and J. Benard. (*Compt. Rend.*, 1954, **239**, Sept., 20, 706–709). Experiments carried out on the oxidation of monocrystalline surfaces of iron at 850° C. and an oxygen pressure of 10^{-3} mm. Hg indicated that oxide formation was greatest in the (110) plane.—T. E. D.

Measured Potentials as Related to Corrosion and Polarization in Local Cells. T. P. May and F. L. LaQue. (*Corrosion*, 1954, **10**, Mar., 91–94). Owing to local cell action, irreversible electrode potentials were found unsuitable as a measure of corrosion rates in sea water. Anodic and cathodic currents were applied in separate experiments to steel in flowing sea water. Polarization curves were constructed from the potentials measured at various current densities. Coupled with corresponding corrosion rates, these potentials permitted the construction of approximate polarization curves for the local anodes and cathodes.—J. F. S.

Effect of Operating Conditions on Corrosion of Hot Water Piping in Buildings. H. L. Shuldener. (*Corrosion*, 1954, **10**, Mar., 85–90). The life of hot water piping can be considerably increased by design, by control of temperature and flow throughout the system, and by good maintenance. Not only joint leaks but corrosion losses will be reduced. Clogging by sediment or corrosion products will thus be lessened. Suggestion for good design, maintenance, and operation are given.—J. F. S.

Sea Water Immersion Trials of Protective Coatings. J. H. Greenblatt. (*Corrosion*, 1954, **10**, Mar., 95–99). Sea-water immersion trials of a variety of types of underwater compositions have shown the superior performance of vinyl finishes, both as protective and antifouling paints. Panel tests, substantiated by shipboard trials, have shown that vinyl finishes can be used on hulls which have a controlled cathodic protection system.—J. F. S.

Some Notes on Hydrogen Blistering. G. A. Marsh. (*Corrosion*, 1954, **10**, Mar., 101–102). Data were obtained on the diffusion of atomic hydrogen through several kinds of steel in acid solutions. Where diffusion occurred, sulphide increased the rate. Sulphide contamination was sometimes difficult to remove.—J. F. S.

Laboratory Methods for Evaluation of Inhibitors for Use in Oil and Gas Wells. E. C. Greco and J. C. Spalding, jun. (*Corrosion*, 1954, **10**, Mar., 103–109). This is a resumé of a report of a technical committee considering standardization of methods of evaluating corrosion inhibitors for oil and gas wells. The methods in use in the U.S.A. are reviewed.—J. F. S.

Three Useful Instruments for the Control of Corrosion in the Petroleum Refinery. J. M. Versteeg. (*Metalen*, 1954, **9**, June 30, 191–197). [In Dutch]. The Audigage is a robust ultrasonic battery-fed instrument for measuring wall thicknesses of material not readily accessible for internal inspection. The electromagnetic Probolog is for the periodical control of non-magnetic piping; it detects reductions in wall thicknesses with an accuracy of $\pm$ 5% thus clearly indicating the locations of pitted and uniform corrosion. The Remotomike is an electropneumatic instrument for determining internal corrosion and eccentricity in piping although pitting may be difficult to detect with it if the pits happen to be filled with

hard deposits. These instruments are obtainable from America and may be of service in other industries.—F. R. H.

Electrolytic Corrosion of Iron and Copper. W. F. Higgins. (*Nature*, 1954, **173**, May 22, 994–995). Examination of a brine heating vessel has revealed that in the presence of graphitized cast iron, copper is anodically dissolved, whereas normal cast iron is less noble than copper. Care is therefore necessary when coupling copper pipes to old cast-iron gas and water mains and in other commercial applications.—A. G.

Mechanism of Filiform Corrosion. W. H. Slabaugh and M. Grotheer. (*Indust. Eng. Chem.*, 1954, **46**, May, 1014–1016). Filiform corrosion occurs under various organic films and metal platings and the filament directions are independent of the qualities of the metal substrate. A mechanism is proposed based on the osmotic diffusion of water through the semi-permeable layer on the surface, and possible remedies are suggested.—A. G.

Thermodynamics of Irreversible Processes Applied to Corrosion. P. A. Johnson and A. L. Babb. (*Indust. Eng. Chem.*, 1954, **46**, Mar., 518–523). A comparison has been made of the electrochemical corrosion rates of commercial steel in dilute potassium chloride as determined experimentally and from the equation due to J. M. Pearson ($i_0 = I_p I_q/(I_p + I_q)$, where i_0 is the corrosion current, and I_p, I_q are the external currents at the discontinuities in the cathodic and anodic polarization curves). Agreement within 10% is reported but may be less good with metals other than iron due to an increased coupling effect.—A. G.

Action of Polar Organic Inhibitors in Acid Dissolution of Metals. N. Hackerman and A. C. Makrides. (*Indust. Eng. Chem.*, 1954, **46**, Mar., 523–527). Theories of cathodic and anodic inhibition are discussed and an adsorbtion mechanism postulated for the action of polar organic inhibitors. Applications of the suggested mechanism to various compounds are considered.—A. G.

ANALYSIS

The Determination of Metallic Iron in Slags and Ores. K. Abresch and R. Dawirs. (*Arch. Eisenhüttenwesen*, 1954, **25**, Sept.-Oct., 409–412). Magnetic separation of metallic iron from slag or ore is usually unsatisfactory as the separated iron often contains up to 30% non-metallic substances. If the iron and ore particles are globular, almost complete separation is obtained. Satisfactory separation can be obtained (1) if the intermittent attraction of the magnetic particles as the poles revolve is smoothed out, and (2) if the magnetic and non-magnetic particles are not in contact while in the field. These conditions prevail when the separation is carried out in a liquid of low surface tension with agitation. Increasing the magnetic flux during separation proved advantageous. Details of the apparatus and procedure are presented.—T. G.

Quantitative Spectrographic Analysis of Basic Open-Hearth Slags. Z. Zíka and L. Röckl. (*Hutnické Listy*, 1954, **9**, (12), 711–715). [In Czech]. A pellet, made by pressing the pulverized sample with copper powder, is sparked on a central stage of the spectrograph, the latter rotating with respect to the second, stationary electrode. The silicon in the sample is used as the internal standard. By means of calibrated photographic plates it is possible to determine CaO, FeO, MgO, MnO, Al_2O_3, Cr_2O_3, SiO_2, TiO_2, and V_2O_5 in a sample in 1½ hr.

Spectrochemical Determination of Rare Elements in Coke Ash and Steel. C. G. Carlsson and A. Larsson. (*Jernkontorets Ann.*, 1954, **138**, (12), 737–743). [In Swedish]. An account is given of the qualitative analysis of ash samples using the D.C. arc, the carrier method, and the double arc. The steel samples were dissolved in HCl and the bulk of the iron removed by ether extraction, this being done twice, once with divalent and then with trivalent iron. The ether solution from the first extraction containing gallium and molybdenum and other elements together with the water from the second extraction were then analysed spectrographically after evaporation on pure carbon electrodes. Germanium was determined separately by the same spectrographic method, after being precipitated as sulphide from H_2SO_4 solution with copper as the carrier element.—G. G. K.

Rare Metal Impurities in Steel Originating from Coke Ash. Å. Josefsson. (*Jernkontorets Ann.*, 1954, **138**, (12), 744–749). [In Swedish]. Details are given of spectrographic analyses for rare elements which might be introduced into pig iron from coke ash and into steel made from coke pig iron. The steels (basic Bessemer) were found to contain 0·0003–0·0005% Ge and 0·0025% Ga. The likelihood of there being significant differences in pig iron manufactured from coke or charcoal due to such elements is discussed and is assumed to be very slight.

Contribution to the Study of Sampling, Reduction, and Analysis of Solid Mineral Fuels. M. Rieffel and V. Danquigny. (*Chaleur et Ind.*, 1954, **35**, Oct., 277–302). All aspects of sampling, size reduction, and analysis of coal and coke are discussed. The effect on analytical results of different operators is shown. Differences due to the manner in which successive steps in grinding were carried out, and due to the various methods of grinding, both manual and mechanical, are demonstrated.—T. E. D.

On the Adsorption Phenomenon in Separation by Precipitation. Part III—On the Determination of W in Fe–W. S. Kiriyama and S. Nishida. (*Sumitomo Metals*, 1952, **4**, May, 310–318). [In Japanese]. Improvements have been made to the conventional method of determination by WO_3 containing impurities. Conditions are established for the rapid and complete precipitation of WO_3 in HCl of definite concentration, there being very little absorption of impurities.

On the Extraction of $FeCl_3$ by Ether in the Determination of Mg in Cast Iron. S. Kiriyama and T. Kishi. (*Fuso Metals*, 1952, **4**, Jan., 277–281). [In Japanese]. To avoid the interference of iron in the determination of magnesium in nodular cast iron, the most suitable conditions for ether extraction of considerable quantities of $FeCl_3$ were determined.—K. E. J.

A Method of Direct Determination of Oxygen Content in Molten Steel. T. Onaka. (*Fuso Metals*, 1951, **3**, July, 159–161). [In Japanese]. Experiments were made with a view to directly determining the oxygen content of molten steel by the potential difference in a cell of molten steel–Ag‖electrolyte‖Ag–H_2.—K. E. J.

On the Rapid Estimation of Mo in Iron and Steel (I). S. Kiriyama and H. Narikawa. (*Fuso Metals*, 1951, **3**, Jan., 31–35). [In Japanese]. Gravimetric methods for Mo are time-consuming and lacking in consistency. A report is presented of an investigation on the lines of the colorimetric method introduced by Klinger.—K. E. J.

Rapid Photometric Determination of Molybdenum in Steel. K. Protiva. (*Chemické Listy*, 1954, **48**, (5), 779–781). [In Czech]. Vollmert's and König's method of determining molybdenum in steel colorimetrically was adapted to facilitate the use of photometry. This method takes 12–15 min. with carbon steels and 20–30 min. with high-alloy steels.—P. F.

Micro-Analysis of Metals by Internal Electrolysis. A. Okáč and L. Sommer. (*Chemické Listy*, 1954, **48**, (8), 1137–1150). [In Czech]. The deposition of bismuth, antimony, and lead was followed during electrolysis in which the anodes consisted of pure lead or aluminium covered with a thin layer of collodion; a platinum grid was used as microcathode. A study of changes of the current and potential with time helped to determine the conditions for the determination (within 1%) of bismuth, antimony, and lead. The method is suitable for the determination of trace elements in unalloyed steel. Copper interferes.—P. F.

The Electrolytic Deposition of Iron As an Analytical Technique. J. O. Lay. (*Metallurgia*, 1953, **48**, Dec., 313–314). Procedures for the electrolytic deposition of iron are examined and the effect of interfering elements is assessed. A technique is recommended which can be employed on a wide variety of materials and confirmatory results are reported.—R. A. R.

Symposium on Fluorescent X-Ray Spectrographic Analysis. (*Amer. Soc. Test. Mat. Spec. Tech. Pub. No.* 157, 1954). This symposium was held at the 56th annual meeting of the Society, at Atlantic City, on June 29, 1953, under the sponsorship of Committee E–2 on Emission Spectroscopy. The papers presented were:

Basic Theory and Fundamentals of Fluorescent X-Ray Spectrographic Analysis. H. Friedman, L. S. Birks, and E. J. Brooks. (3–26).

The Correlation between Fluorescent X-Ray Intensity and Chemical Composition. J. Sherman. (27–33).

Use of Multichannel Recording in X-Ray Fluorescent Analysis. M. F. Hasler and J. W. Kemp. (34–42).

Examination of Metallic Materials by X-Ray Emission Spectrography. R. M. Brissey, H. A. Liebhafsky, and H. G. Pfeiffer. (43–56).

An Absolute Method of X-Ray Fluorescence Analysis Applied to Stainless Steels. G. E. Noakes. (57–62).

The Fluorescent X-Ray Spectrographic Analysis of Minerals. H. F. Carl and W. J. Campbell. (63–68).

Index to the Literature on Spectrochemical Analysis, Part III—1946–1950. B. F. Scribner and W. F. Meggers. (*Amer. Soc. Test. Mat. Spec. Tech. Pub. No.* 41–c, 1954).

Direct-Reading Metal Spectroscopy with a D.C. Arc. S. C. Baker. (*Brit. J. Appl. Phys.*, 1954, **5**, June, 215–219). Using a wavelength spectrometer adapted for direct-reading by the null indication of a cathode-follower bridge circuit and a D.C. globule arc, a linear relationship between the manganese concentration in steel and the Mn-4754/Fe-5455·6 intensity ratio has been obtained over the range 0·3%–1·3% Mn with a standard deviation of 2%. Photographic methods for Mn-4754/Fe-4707·3 give a standard deviation of 4%. Although the volt-ampere characteristic of the arc is discontinuous, a working curve can be prepared which is parallel to the current axis over the required range.—J. O. L.

Determination of Free Lime in Slag. H. Gotô and Y. Kakita. (*Nippon Kinzoku Gakkai-Si*, 1952, **16**, July, 394–395). [In Japanese]. It was found that free lime in several types of open-hearth slag could be estimated by McPherson and Forbrick's method for cement (extraction with ethylene glycol and titration with hydrochloric acid). Results were readily obtained in 30 min.—K. E. J.

HISTORICAL

Results of Investigations of Ancient Bloomery Slags. W. Oelsen and E. Schürmann. (*Arch. Eisenhüttenwesen*, 1954, **25**, Nov.-Dec., 507–514). Excavations in Schleswig-Holstein revealed the extensive use of the bloomery process in prehistoric times. Samples taken from sites were analysed and the slags were classified into those found inside and outside the furnaces.—T. G.

A Brief Survey of the Early History of Woolwich Arsenal. O. F. G. Hogg. (*Manchester Assoc., Eng.*, Advance Copy, Nov. 12, 1954).

The Centenary of the Société Métallurgique D'Imphy. (*Techn. Civil.*, 1954, **3**, (4), 129–133). The history of the company from its founding in 1854 onwards is surveyed, but it is pointed out that excellent anchors were made here in the second half of the 17th century.—R. A. R.

Investment in the Scottish Pig Iron Trade 1830-1843. R. H. Campbell. (*Scottish Journal of Political Economy*, 1954, **1**, Oct., 233–249).

An Industry Grows. (*E.S.C. News*, 1954, **8**, (2), 3–10). An historical survey is given of the development of associated companies of the English Steel Corporation in the latter half of the 19th century.—L. D. H.

Henry Bessemer. E. N. Simons. (*Metallurgia*, 1954, **50**, Nov., 231–235).

BOOK NOTICES

COMSTOCK, GEORGE F. "*Titanium in Iron and Steel.*" (Alloys of Iron Research Monograph Series.) 8vo, pp. xii + 294. Illustrated. New York, 1955: John Wiley and Sons, Inc.; London: Chapman and Hall, Ltd. (Price 48*s*.).

This book is one of a series of monographs on alloys of iron published by the Engineering Foundation of the U.S.A. The present volume is intended to cover all the important data on titanium as a minor addition element in iron and steel, and it appears to fulfil its purpose extremely thoroughly. Briefly, the effects of adding titanium to an iron or steel can be largely explained in terms of its marked chemical affinity for the non-metallic elements oxygen, nitrogen, carbon, and sulphur. When added to an iron alloy containing such non-metallic elements, titanium will, therefore, eliminate the effects of either the chemical or the metallurgical reaction of these elements with the iron alloy by combining with them to form inert compounds. The author's outlook is, however, severely practical, and no pretence at a truly scientific account of the effects of titanium in iron and steel is made. The book must, therefore, be considered as essentially a reference book.

Quite understandably, in a highly specialized monograph of this type, it is assumed that the reader is familiar with all the diverse effects of minor addition elements on the properties of steels and cast irons. Each chapter is, therefore, devoted to a detailed consideration of the results of adding titanium to a particular type of iron alloy such as, for example, wrought, cast, alloyed or unalloyed steels. Cast irons are considered together in a single chapter. At the end of each chapter the author has appended a brief summary of its contents. These summaries will no doubt prove to be useful to anyone using the book in helping him to select for detailed reading those chapters which may best serve his interests; they are, however, too brief to give in themselves any indication of the scope or contents of the book.

The book concludes with a bibliography which appears to contain all the significant references to the effects of titanium on iron and steel. This bibliography, which is arranged in chronological order, covers the period up to the middle of 1953.—A. D. MCQUILLAN.

CONSERVATOIRE DES ARTS ET MÉTIERS. "*Formation du Grain dans les Métaux par Recrystallisation.*" Semaine d'Etude de la Physique des Métaux, 1952, organisé avec le patronage de la Société Française de Métallurgie. La. 8vo, pp. 123. Illustrated. Paris, 1955: Editions Métaux. (Price 1500 frs.).

This consists of ten papers on recrystallisation and grain growth, delivered at a week's symposium on the subject held in 1952. All have since appeared in "*Métaux–Corrosion–Usine*" and, with the exception of two dealing with non-ferrous aspects, have been abstracted in the *Journal*.—J. P. S.

DEPARTMENT OF DEFENSE, WASHINGTON, D.C. "*Cross-Index of Chemically Equivalent Specifications and Identification Codes (Ferrous and Non-ferrous).*" Supply and Logistics Handbook: Standardization H 1R, Superseding DSMA H1. La. 4to, pp. ix + 345. Washington, D.C., 1954: United States Government Printing Office. (Price $1.75).

This is a revision of an earlier volume prepared by a joint Army/Navy/Air-Force group in conjunction with the engineering staff of the General Motors Corp. Upon this earlier one the well-known "*Steel's* Specifications Handbook" was based; like it, the present compilation contains a Part I, wherein chemically equivalent specifications are grouped under headings such as *Iron-Base Alloys*, *Copper and Copper-Base Alloys*, etc., in each group being found the number of the specification (Federal Specifications, U.S. Army, A.S.T.M., S.A.E., A.I.S.I., etc.) and the specified composition. These are further grouped to bring all those of a similar analysis together. Next comes a Part II where the names and numbers of the specifications are listed under the issuing bodies, together with a code-number relating to the serial order of Part I. Part III lists the nominal compositions of the contents of Part I, by code order, and description, without naming specifications or their numbers: this gives an easy way to find, by cross-reference to Part I, what are the specifications for a steel with 0·23% carbon, 0·45% manganese, or a cartridge brass with 70% copper, 30% zinc. There are five specifications that cover the former, and 24 the latter.

This should be very useful to those who wish to compare American specifications one with another, but does not, of course, provide any comparisons with the specifications of other countries.—J. P. S.

DEUTSCHE GESELLSCHAFT FÜR CHEMISCHES APPARATEWESEN E.V. "Dechema – Werkstoff – Tabelle." "*Chemische Beständigkeit der Werkstoffe.*" 3. Bearbeitung. Folio, loose-leaf. 4. Lieferung. 100 sheets (200 pp.). Weinheim-Bergstrasse [1955]: Verlag-Chemie G.m.b.H. (Price DM. 0.30 per sheet).

Earlier parts of this compilation have been reviewed in the *Journal* (1954, **177**, July, 385; 1955, **179**, Jan., 102); this volume proceeds from *Butan* (butane) to *Cavit* (described as a mixture of aliphatic acids and aldehydes). In between come, for example, butter-milk, Caro's acid (H_2SO_5) and casein; the list of substances, with their degree of susceptibility to attack, and the valuable notes, remain the same.—J. P. S.

EULER, HANS, and HANS STEVENS. "*Die Analytische Arbeitsbewertung als Hilfsmittel zur Bestimmung der*

Arbeitsschweirigkeit." Unter Mitarbeit des Fachausschusses Arbeitstudien, Arbeits- und Leistungsbewertung. 3. Auflage. (Socialwirtschaftliche Schriftenreihe, Heft 3. Herausgegeben vom Ausschuss für Sozialwirtschaft der Wirtschaftsvereinigung Eisen- und Stahlindustrie.) Folio, pp. 87. Düsseldorf, 1954: Verlag Stahleisen m.b.H. (Price DM. 9.60).

Faced with the urgent need for thorough-going reorganization after the last war, the German industry has adopted the technique of job evaluation probably to a greater degree than any other country outside the U.S.A. It was first introduced by certain individual works, in agreement with the works council, for an initial period of three months. In each case, both workers and management agreed at the end of the trial period that it represented a great improvement on previous practice; and although adoption of the system was estimated to add some 3–6% to the wages bill, this was said to be balanced by increased output, better team work, fewer wage claims, and reduced labour turnover amongst lower paid workers. By early 1952, the basic wage rates of some 80,000 manual workers in the German iron and steel industry had been fixed on the basis of the job evaluation system, and that figure had more than doubled by the following year. The original study by Euler and Stevens has been widely used throughout the German industry as a basis for introduction of the system; and although the current third edition is still basically the same as the first and second, the authors have been able to incorporate practical experience gained since publication of the first edition in 1950. Thus the book discusses the technique of job evaluation not only from the purely theoretical but also from the practical point of view, giving useful tables with examples of technical ability required for certain jobs in the blast-furnace plant, steel melting shop, rolling mill, etc.; a specimen job evaluation form which can be adapted for use in each department; and twenty pages of detailed discussion of some 60 typical jobs, with reference to accident dangers involved in certain types of work. In the new edition, the slight improvements made to the original tables, and the clarification and expansion of the text itself, enhance the value of this most useful work.

"*Organic Reagents for Metals and Other Reagent Monographs.*" Vol. I. By the Laboratory Staff of Hopkin and Williams, Ltd. Edited by W. C. Johnson. Fifth edition, 8vo, pp. viii + 199. Illustrated. Chadwell Heath, Essex, 1955: Hopkin and Williams, Ltd. (Price 15*s.*).

This volume consists of 27 monographs, 23 of which relate to reagents which are used in the determination of metals, compared with 43 such monographs in the fourth edition of "Organic Reagents for Metals," published in 1943. The publishers commenced in 1950 to issue revised monographs dealing with the various reagents singly, and so far 14 of these have appeared; these 14 and 13 other new or revised monographs make up the volume under review. The inclusion of reagents for the determination of water, phenols and amino acids in a book mainly dealing with the determination of metals is a little odd and hardly justified by the explanation given in the preface; surely it would have been preferable to rewrite three or four more of the monographs which appeared in the fourth edition, e.g. those on cupferron, dithizone, and quinaldinic acid. Among the new reagents discussed are chloroanilic acid, ethylene-diaminetetra-acetic acid, and phenylfluorone.

The monographs in this edition are a great improvement on those in the earlier edition, in that much more detailed instructions are given for the use of the individual reagents and the effect of interfering elements is more fully discussed.

The bibliographies given at the end of every monograph are complete and up-to-date, and add greatly to the value of the work.

The book is well arranged, printed in clear type on good paper, and particularly free from misprints; it is a worthwhile addition to the library of all who have to determine non-ferrous metals, but contains little direct information on the application of organic reagents in steelworks analysis. It is to be hoped that the authors will not unduly delay the preparation of a second volume covering those reagents which have so far been omitted from this edition and including some of the newer organic reagents which have been developed in recent years.—A. R. Powell.

Organisation for European Economic Co-operation. "*Powder Metallurgy.*" (Technical Assistance Mission No. 141). La. 8vo, pp. 309. Illustrated. Paris, 1955: The Organisation.

Technical Assistance Mission No. 141, studying powder metallurgy in the United States of America, comprised 28 members, representing seven European countries, including the United Kingdom. Their technical interest was of the widest, and in five weeks in October–November, 1953, they made 43 visits to manufacturing plants, universities, and research establishments; they also visited the 35th National Metal Congress and Exposition at Cleveland, Ohio. The report is largely one of practical detail; it is evident that a large amount of information was supplied to them at each plant they called upon and that it has been somewhat uncritically recorded. The conclusions, however, are of some interest, and can be briefly summarized as follows: Technique and equipment in the U.S.A. are in no way better than in Europe, but the wider use, and greater production, of powder metallurgy parts have made it possible to use the equipment, and to employ tungsten carbide dies, to great economic advantage.—J. P. S.

Poppe, Kurt (Editor). "*Zeitmessgeräte für die Industrie.*" Herausgegeben von der Energie- und Betriebswirtschaftsstelle des Vereines Deutscher Eisenhüttenleute. 8vo, pp. vii + 156. Illustrated. Düsseldorf, 1955: Verlag Stahleisen m.b.H. (Price DM. 18.–).

This publication gives a survey of commercial time-measuring instruments which are at present available, and explains their principles and applications as required by the production engineer to decide whether this or that instrument might be of use for measuring and recording phenomena in his plant. Almost all details of design are intentionally excluded, except for a few sketches showing principles with particular regard to electronic instruments. While this booklet is originally intended for engineers in iron and steel works, the work seems to have developed to a comprehensive survey of time-measuring instruments in general. The recommendations given for the selection of instruments are rather short and could have been extended much more; for instance, the expressions 'accuracy of indication' and 'sensitivity of indication,' which are connected, are not discussed in detail. A large number of the instruments described are provided with recording and registering devices, and here also, some more information could have been given on the behaviour of paper, pens, etc. Most of the illustrations show the instruments only from the outside, occasionally with the covers removed, but here also only the expert may be able to distinguish differences in design. Instruments of 19 German producers and one Swedish firm are considered and no reference is made to the highly developed instruments produced in America, England and France. At the end of the book a list is given of the 94 instruments described, indicating the actual producer and also the producers of similar instruments. In addition the price range of the instruments in question is stated.

The lack of detailed information on the working of the instruments is mitigated by the fact that the German technical literature has two good handbooks on this subject, i.e. A. Palm, "*Registrierinstrumente,*" Springer Verlag, Berlin, 1950, and P. M. Pflier, "*Elektrische Messung mechanischer Grössen,*" Springer Verlag, 1948. However, in American and English literature the reviewer was not able to trace a similar work. Therefore, an English translation of this book would probably be very useful.—P. Grodzinski.

Sully, A. H. "*Manganese.*" (Metallurgy of the Rarer Metals, No. 3.) 8vo, pp. xii + 305. Illustrated. London, 1955: Butterworth's Scientific Publications. (Price 40*s.*).

The publication of this third monograph in the series on the rarer metals is a reflection on the present times. That one of the less common metals, manganese, should form the subject matter of a complete volume demonstrates the vast expansion in the frontiers of metallurgical knowledge and the increased recognition of the importance of metallurgy, which have occurred in the past twenty years.

The book may be described as an accomplished compilation of information on the metallurgy of manganese, based on 470-odd references. Out of a total of 300 pages, 120 pages deal in one way or other with production: they

cover manganese ores, the processes used to extract manganese in the pure form and as ferro-alloys, conservation of manganese in steelmaking, and the treatment of low-grade materials. The remainder of the book is concerned with the physical properties and alloying behaviour (including a valuable collection of equilibrium diagrams) of manganese, concluding with a short discussion on various topics such as workability, electrodeposition and oxidation.

The volume is well produced, with the text clearly expressed, and in the main the illustrations are appropriate. However, there are a number of full-page photographs of such things as mining and jigging methods and an aerial view of a works, which use up space far in excess of their value to any readers, let alone to metallurgists. The author should be congratulated for collecting and summarizing this comprehensive account of the metallurgy of manganese.
A. R. BAILEY.

TÖDT, FRITZ (Editor). "*Korrosion und Korrosionsschutz.*" La. 8vo, pp. xxxii + 1102. Illustrated. Berlin, 1955: Walter de Gruyter and Co. (Price DM. 168.–).

Over three thousand papers appear each year on topics relating to the corrosion of metals and alloys. Therefore a book summarizing the present state of knowledge of this subject is particularly welcome and opportune, since most of the available texts are several years out of date.

Tödt and his nineteen collaborators have divided the subject into five main sections: General, intercrystalline and stress corrosion; corrosion of the various metals; methods of corrosion prevention; corrosion in different industries; and corrosion testing methods. The more recent literature has been surveyed. The chapters on corrosion in industry will be of great value to engineers with corrosion problems, and the short accounts of the use of silicones and fluorinated hydrocarbons in corrosion prevention will be of especial interest. The section on testing methods is rather inadequate, and insufficient attention is paid to the statistical interpretation of results, but a useful bibliography of papers published since 1950 is appended.

In a collaborative work of this kind the editing is very important. This book includes some unnecessary repetition of subject matter and also diagrams. Numerous irritating errors and irregularities occur in the references. In the chapter on iron, for example, misprints of authors' names are common, the titles of papers are only given in certain cases and foreign titles are occasionally translated into German.

The format is excellent, the diagrams and photographs are clearly reproduced, the print is clear and easy to read and the index, running to over thirty pages, has been well prepared. At DM. 168, however, the book will be beyond the purse of most private individuals.—GEORGE BUTLER.

NEW PUBLICATIONS

AKSJONOW, N. P., and P. N. AKSJONOW. "*Ausrüstung von Giessereien.*" Vol. II. Uberstetzung aus dem Russischen. 8vo, pp. 520. Illustrated. Berlin, 1953: VEB Verlag Technik. (Price DM. 25.–).

AMERICAN FOUNDRYMEN'S SOCIETY. "*Control of Emissions from Metal-Melting Operations.*" La. 8vo, pp. ii + 26. Illustrated. Des Plaines, Ill. [1955]: The Society. (Price $2.25; $1.50 to members of the A.F.S.).

AMERICAN IRON AND STEEL INSTITUTE. "*Annual Statistical Report*, 1954." 8vo, pp. vii + 9–130. New York, 1955: The Institute.

AMERICAN IRON AND STEEL INSTITUTE. "*Cold Rolled Carbon Steel Strip.*" (A section of the Steel Products Manual, revised February, 1955.) La. 4to, pp. 27. Illustrated. New York, 1955: The Institute.

AMERICAN IRON AND STEEL INSTITUTE. "*High Strength Low Alloy Steel.*" (Steel Products Manual, May, 1955.) La. 4to, pp. 45. Illustrated. New York, 1955: The Institute.

AMERICAN IRON AND STEEL INSTITUTE. "*Hot Rolled Carbon Steel Strip.*" (A section of the Steel Products Manual, revised March, 1955.) La. 4to, pp. 24. New York, 1955: The Institute.

AMERICAN IRON AND STEEL INSTITUTE. "*Tool Steels.*" (Steel Products Manual, April, 1955.) La. 4to, pp. 72. Illustrated. New York, 1955: The Institute.

BAKER, C. "*Technical Publications. Their Purpose, Preparation and Production.*" 8vo, pp. xiii + 302. Illustrated. London, 1955: Chapman and Hall, Ltd. (Price 36*s.*).

BATRAKOW, W. P. "*Korrosion Metallischer Werkstoffe in aggressiven Mitteln.*" 8vo, pp. 511. Illustrated. Berlin, 1954: VEB Verlag Technik. (Price DM. 54.–).

BOCKRIS, J. O'M. (Editor). "*Modern Aspects of Electrochemistry.*" 8vo, pp. xii + 344. Illustrated. London, 1954: Butterworth's Scientific Publications. (Price 40*s.*).

BRITISH IRON AND STEEL FEDERATION. "*Statistical Year Book for* 1953." Part II. "*Overseas Countries.*" La. 4to, pp. xvi + 437. Illustrated. London, 1955: The Federation. (Price 15*s.*).

BRITISH IRON AND STEEL FEDERATION. "*Statistical Year Book for* 1954. *United Kingdom Statistics.*" La. 4to, pp. vii + 151. Illustrated. London, 1955: The Federation. (Price 7*s.* 6*d.*).

BRITISH STANDARDS INSTITUTION. B.S. 1121: Part 34: 1955. "*Methods for the Analysis of Iron and Steel.*" Part 34. "*Molybdenum in Iron and Steel* (*Absorptiometric Method*)." 8vo, pp. 8. London, 1955: The Institution. (Price 2*s.*).

BRITISH STANDARDS INSTITUTION. B.S. 1121: Part 35: 1955. "*Methods for the Analysis of Iron and Steel.*" Part 35. "*Aluminium in Iron, Steel and Ferro-Alloys (after Mercury Cathode Separation).*" 8vo, pp. 8. London, 1955: The Institution. (Price 2*s.*).

BRITISH STANDARDS INSTITUTION. B.S. 1121 C: 1955. "*Recommended Method for Mercury Cathode Electrolysis for Use in the Analysis of Iron, Steel and Ferro-Alloys.*" 8vo, pp. 9. Illustrated. London, 1955: The Institution. (Price 2*s.* 6*d.*).

BRITISH STANDARDS INSTITUTION. B.S. 1374: 1955. "*Log-Sheets for Steam and Hot Water Boiler Plants.*" 8vo, pp. 16. London, 1955: The Institution. (Price 3*s.*).

BRITISH STANDARDS INSTITUTION. B.S. 2590: 1955. "*Sintered Metal Powder Components.*" 8vo, pp. 16. Illustrated. London, 1955: The Institution. (Price 3*s.*).

BUREAU OF MINES. "*Minerals Yearbook, Fuels, Volume II*, 1952." Prepared by the Staff of the Bureau of Mines, Fuels and Explosives Division. 8vo, pp. vii + 450. Illustrated. Washington, D.C., 1954: Government Printing Office. (Price $2.25).

BURNS, R. M., and W. W. BRADLEY. "*Protective Coatings for Metals.*" Second edition. 8vo, pp. xiv + 643. Illustrated. New York, 1955: Reinhold Publishing Corp. (Price 96*s.*).

CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE. "*Centre d'Etudes de Chimie Métallurgique.*" La. 8vo, pp. 70. Illustrated. Vitry-sur-Seine (Seine), France [1954]: Le Centre.

COMSTOCK, GEORGE. "*Titanium in Iron and Steel.*" (Alloys of Iron Research.) 8vo, pp. xii + 294. Illustrated. New York, 1955: Wiley and Sons; London, Chapman and Hall, Ltd. (Price $6, 48*s.*).

COTTRELL, A. H. "*Theoretical Structural Metallurgy.*" Second Edition. 8vo, pp. viii + 251. Illustrated. London, 1955: Edward Arnold (Publishers), Ltd. (Price 25*s.*).

DEPARTMENT OF DEFENSE, WASHINGTON, D.C. "*Cross-Index of Chemically Equivalent Specifications and Identification Codes* (*Ferrous and Non-ferrous Alloys*)." Supply and Logistics Handbook: Standardization H 1A, superseding DSMA H1. La. 4to, pp. ix + 345. Washington, D.C., 1954: United States Government Printing Office. (Price $1.75).

DEUTSCHE GESELLSCHAFT FÜR CHEMISCHES APPARATEWESEN, E.V. "*Dechema-Werkstoff-Tabelle.*" Chemische Beständigkeit der Werkstoffe. 3. Bearbeitung. Folio, loose-leaf. 4. Lieferung. 100 sheets (200 pp.). Weinheim-Bergstrasse [1955]: Verlag-Chemie G.m.b.H. (Price DM. 0.30 per sheet).

DE VRIES, LOUIS. "*English-German Technical and Engineering Dictionary.*" 8vo, pp. 997. New York, 1954: McGraw-Hill Book Co., Inc. (Price $20.00).

DRÖGE, WILHELM. "*Der Stahlwerker.*" Bd. 1. "*Eine kleine Wanderung durch die Gebiete der Chemie und Physik.*" 8vo, pp. 213. Illustrated. Leipzig, 1955: Fachbuchverlag. (Price DM. 14.–).

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